M. Rain-On-Snow

The Rain-On-Snow guidance memo specifically explains the procedures to be followed when applying the rain-on-snow rule (WAC 222-22-100(2)) and some of the science behind peak flows and rain-on-snow events. Both the rain-on-snow rule guidance memo and rule are incorporated into the Forest Practices Habitat Conservation Plan.

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Grizzel

WASHINGTON STATE DEPARTMENT OF
Natural Resources

BRIAN BOYLE
Commissioner of Public Lands

OLYMPIA, WA 98504

September 26, 1991

TO: REGIONAL MANAGERS

Jack Hulsey, Forest Practices Division Manager Jack

Implementation of Rain-on-snow: **WAC 222-16-046 (7)**

The department has the responsibility to implement rules adopted by the Forest Practices Board. The recent rule regarding rain-on-snow and clearcut size directed the department to implement a new type of rule. This rule required the use of a new approach in the regulation of forest resources. The rule obligates the department to take a broader look at the landscape ~~and departs~~ from the reliance on regulations that only apply to the circumstances of a single application.

The department is committed to an "adaptive implementation" approach. I feel that our implementation strategy is sound. However, due to the complexities of the current rules that interact with existing harvest patterns and resource conditions, there may be unintended consequences.

I firmly believe that we need to give this approach an operational test, learn more by doing and make adjustments as necessary. With your cooperation, implementation will be successful and consistent with the overall policy objectives of RCW 76.09.

Beginning on October 1, 1991 the department will implement WAC 222-16-046 (7) as outlined below.

22-100(2)

RAIN ON SNOW: WAC 222-~~16-046(7)~~

OVERVIEW

Using emergency rules, the Forest Practices Board directed the department to "condition the size of clearcut harvest applications in the significant rain-on-snow zones". Using "local evidence" to verify that peak flows "have resulted in material damage to public resources", the department has developed conditioning strategies based on reducing but not eliminating the potential for increased risk to public resources. Such an approach is seen as consistent with the provisions of RCW 76.09.010.

The approach is based on the understanding of how streamflows can be increased[1] by timber harvest in the significant rain-on-snow zones. Operating on the assumption that moving more water more frequently through a stream is damaging, the size of clearcuts would be conditioned to reduce the risk to public resources. Alternative harvest practices, such as strip cutting or partial cutting, are permitted with restrictions. The restrictions are designed to retain harvest options while moderating hydrologic impacts and attendant risks to public resources.

BASIC PRINCIPLES

Snow retention is modified by the nature of the forest canopy. Removal of the forest's canopy increases snow accumulation. The canopy also has a major influence on the rate of snow melt which is strongly controlled by energy movement into the snowpack. When the forest is immature or recently harvested, wind and rain can more rapidly move energy into the snowpack, substantially accelerating the rate of melt.

It is the combination of young forests (i.e. hydrologically immature), increased snow accumulation, and potential rapid rates of melt, that can increase the severity of storm effects. Channels unaccustomed to elevated storm intensities and frequencies can be degraded, producing material damage to public resources.

The conditioning strategies are based on the idea that there is not a likelihood that damage may be associated with rain-on-snow events unless certain conditions exist. There must be a reasonable amount of the basin in the significant rain-on-snow (ROS) zones and there must be enough of the basin that is hydrologically immature (HI). Thus, there are relationships between the proportion HI and proportion in the ROS zones and the potential increase in water available for runoff. These relationships are used to define Risk Classes (A,B or C: see Attachments 1,2, or 3) that set general limits on the use of conditioning on an individual application.

Due to regional climatic differences within Washington, the department has divided the state into three response zones. They are west of the Riparian Management Zone line ("western" Washington), east Cascades and Okanogan Highlands, and Pend Oreille and Blue Mountains. For each graph, two lines were developed that define the limits of **Risk Classes A, B or C**. Basins below the first line are in **Risk Class A**; basins between the two lines are in **Risk Class B**; basins above the second line are in **Risk Class C**. Risk classes directly relate to the likelihood of material damage to a public resource which is associated with peak flows.. As such, the risk classes are used to set general limits on conditioning clearcut size. Please refer to **CONDITIONING STRATEGIES**.

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[1] Please see Appendix One, Technical Background, for an explanation of the scientific rationale that underpins this regulatory approach.

Before any conditions are applied to an application, all the following circumstances must occur:

1
1. The application must be in a significant ROS zone.

2
2. There are preliminary indications of "local evidence of peak flows which have resulted in material damage to public resources".

3. There are significant amounts of hydrologic immaturity in the basin.

4. An Interdisciplinary Team (IDT) has reviewed the previous three points and has provided recommendations to the department.

5. The department develops conditions that reflect the on-the-ground facts and recommendations of the IDT.

The lower lines on Attachments One, Two and Three define where, under modeled storm conditions, there can be an one-inch increase of water available for runoff. This is in addition to whatever direct precipitation may have occurred during the 24-hour storm event. (All calculations are based on 24-hour storm data.) The increment is due to the impact of accelerated melt of an increased snowpack in hydrologically immature areas. The net result is that a 10-year storm now approximates a 50-year storm.

The line in the upper right corner of the graphs corresponds to a two-inch increase of water available for runoff. This increment of water magnifies 10-year storm into a 100-year storm. So the stream now "feels" as if there has been a 100-year storm when precipitation onto hydrologically mature forested areas approximate a 10-year storm.

The approach is based on Type 3 streams. These are small enough to geographically focus attention on material damage to public resources ; they are closest to the possible site(s) that may have influenced storm intensities. Trying to assess impacts on larger streams is much more difficult, particularly if the objective is to geographically isolate probable areas of concern. The intent is to determine damage at the lower reaches of Type 3 streams[2]. It is in the lower reaches of T-3 streams that the contribution of ROS impacts can be most reasonably detected.

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[2] The routine focus will be on the lower reaches of T-3 streams. However, based on the site-specific facts, upper reaches of T-3 can be reviewed when appropriate. Likewise, for T-4 or T-5 streams where sediment/debris avalanches could reach type 1,2, or 3 and have produced material damage to public resources, WAC 222-16-046 (7) may be applied.

Calculations of HI will be done on the portions of the T-3 basin that are in the significant ROS zones (i.e., the peak rain-on-snow and the snow-dominated precipitation zones). Please see Attachment Four. Unless site-specific factors dictate otherwise, HI is assumed to end at 25 years (total) age for areas west of the RMZ line and 35 years (total) for all other locations. For purposes of the calculation of HI, a pending or approved application should be treated as if it was completed.

CONDITIONING STRATEGIES

The conditioning strategies for ROS employ the concept that any given applications are controlled by maximum[3] permitted clearcut size, dependent on the particular risk class. Subject to the site-specific conditions, such as slope, aspect, nature of damage and age-class distribution, an application could have clearcut harvest size reduced below the maximum.

OPERATIONS WITHIN RISK CLASS A

Routinely, no additional clearcut harvest restrictions for ROS would be applied. Any ROS conditioning within Risk Class A would be on an exception basis, and done after a review of the site-specific facts after consultation with the Forest Practices Division. Existing rules and BMP's would guide routine conditioning.

OPERATIONS WITHIN RISK CLASS B

Individual clearcuts would be limited to 80 acres[4]. Alternatives to clearcutting would be considered[5]. Multiple 80 acre operations are being envisioned as being acceptable, dependent upon the facts within the sub-basin.

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[3] The maximum sizes or alternatives to clearcuts will generally control the conditioning actually applied. Exceptions to the conditioning strategies will be approved on an individual basis after consultation with the Forest Practices Division.

[4] Each application would be evaluated in the light of the sub-basin "facts". Size could be reduced. Eventually, as applications accumulate, the sub-basin could move into Risk Class C where more stringent conditioning would be applied.

[5] Strip-cutting up to 35% of the remaining acres of mature timber would be considered as another type of maximum. Partial-cutting up to 45% of the remaining volume of the hydrologically mature timber would be considered as another type of maximum. Clearcut harvest may be reduced below either of these maxima dependent upon sub-basin conditions.

OPERATIONS WITHIN RISK CLASS C

Clearcutting within areas of Risk Class C would be substantially restricted. Clearcut size is reduced to zero until there is a change in the state of hydrologic maturity, i.e., the portion of older stands increases to move the sub-basin into risk Class B or Risk Class A. Alternatives to clearcutting would be considered[6].

INDICATORS OF MATERIAL DAMAGE TO PUBLIC RESOURCES

The method recommended by DNR for evaluating the existence of material damage to stream channels is the "Stream Channel Stability Evaluation Form" from USFS Hydrologist Dale Pfankuck's work in the 1970's. The form arrays indicators of upper bank, lower bank, and channel bottom condition across four condition levels(Appendix 2). This is an interim channel evaluation method, and may be augmented or changed later.

HOW THE RULE WILL BE APPLIED

No conditioning under this rule should be applied until several steps have occurred. As in other circumstances, compliance with all rules, particularly road maintenance and abandonment, should be reviewed. Subsequently, there are five key events.

1. The application must be in a significant ROS zone

   The department has mapped the five major precipitation zones (Attachment Four). For the purposes of this rule, the snow dominated and the rain on snow precipitation zones are considered <u>significant</u>. Attachment One explains their derivation. The department's Geographical Information System (GIS) has the base data and maps can be produced on an as needed basis. Additional information on storm intensities and precipitation are also available on the GIS.

   (3) Generally, in western Washington, the significant rain on snow zones starts near 1,600-1,800 feet and extends to approximately 4,000 elevation. These numbers are only for the purposes of illustration. Please use the actual GIS data/maps are the numbers vary dependent on regional climatic differences, aspect, and other factors.

   Upon receipt of an <u>application</u>, the department will make an initial determination that the proposed operation is in the significant rain

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[6] Strip-cutting up to 20% of the remaining acres of mature timber would be considered as another type of <u>maximum</u>. Partial-cutting up to 30% of the remaining volume of the mature timber wold be considered as another type of <u>maximum</u>. Dependent upon the nature and extent of material damage to public resources, these percentages could be reduced.

on snow zone. This will be noted on the application. The application is mailed for comment.

2. There are preliminary indications of "local evidence of peak flows which have resulted in material damage to public resources".

FPA recipients are asked for a timely review. If there is no timely[7] response or the response is that there are no indications of damage, then the application will be processed as any other application. If there are responses that there is "damage", the department will move to step three[8].

3. There are significant amounts of hydrologic immaturity in the basin.

The department will ask the landowner to provide information regarding stand age in a sub-basin[9]. Age-class data is needed only for that portion within the significant rain on snow zones. Only very broad stand age data is necessary. For west of the RMZ line, acres of stands with (total) age 25 years or less is needed. For other locations, the age is 35 years or less.

4

If the sub-basin is not totally under the ownership of the applicant, then the department will use photos or sources to determine the extent of hydrological immaturity.

Depending on location, Attachment One, Two or Three is used to assess Risk Class. Using the percent of the sub-basin that is in the snow dominated and rain on snow precipitation zones and the percent of HI within the these two zones, the graph is used to "calculate" Risk Class. If the application is Risk Class A, the application would not generally be subject to this rule; other rules, BMP's or conditioning for other purposes would still apply.

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[7] FPA recipients will be asked for their responses within ten business days from the date of transmittal. WAC 222-20-020 imposes time limits that require a timely response since the the remaining steps are constrained by this rule. Consideration of late responses will be on a case-by-case basis only.

[8] Assessment of "local evidence of peak flows which have resulted in material damage to public resources" is a key step. Initially the department will use the approach outlined in Appendix 2 as a guideline for DNR decisions. Responding parties are encouraged to understand and use Appendix 2 as a basis for assertions of material damage. damage metric

[9] Generally, the calculations and assessments will be on a Type 3 stream map; also, see footnote 2. The water type maps will initially be the base for determining T-3 sub-basins.

If the proposed application is in Risk Class B or C, continue to step 4.

4. An Interdisciplinary Team (IDT) has reviewed the previous three points and has provided recommendations to the department.

5 The department will convene an IDT to site-specifically assess the facts. If the department agrees will the IDT's assessment that the first three steps have been correctly taken, then the IDT will be asked for conditioning recommendations. The following should be considered during the IDT process:

* nature and extent of peak flow damage
* age-class patterns within the sub-basin
* slope and channel stability factors
* resources at risk
* size and extent of previous harvests
* limitations of alternative silvicultural systems

The previous considerations are not intended to be an exclusive list. The department will consider any appropriate factors during the development of the sub-basin, basin or site-specific conditions.

6 5. The department develops conditions that reflect the on-the-ground facts and recommendations of the IDT.

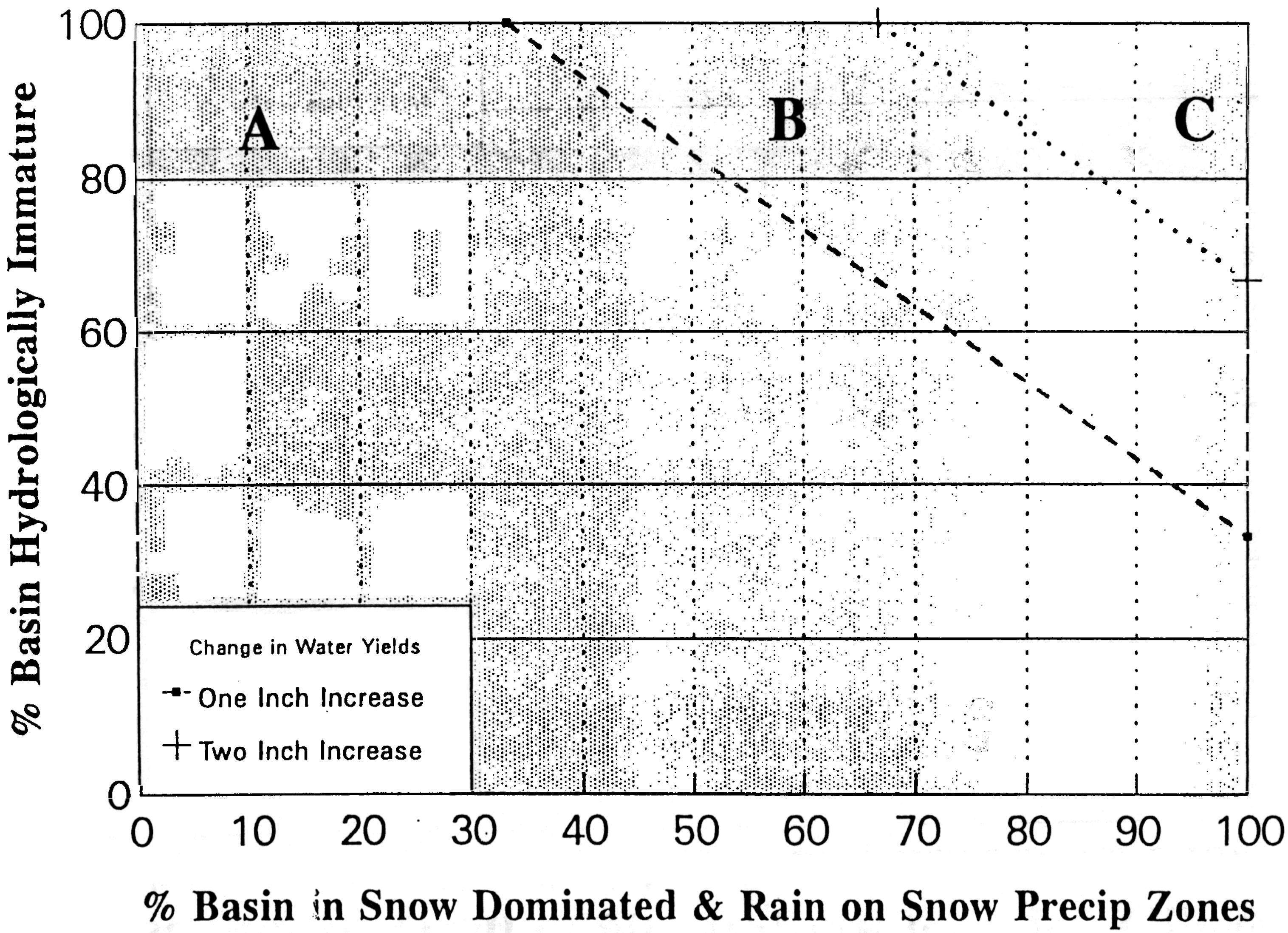
The department conditions the application consistent with RCW 76.09. The content of any conditions is the statutory responsibility of the department.

attachments
appendices

c: Forest Practices Board
Art Stearns, Supervisor
Laura Eckert, Deputy Supervisor
Ted Price, Deputy Supervisor
Pat McElroy, Deputy Supervisor
Forest Practices Board Liaisons
Bill Jacobs, WFPA
Jim Anderson, NWIFC
David Bricklin, WEC

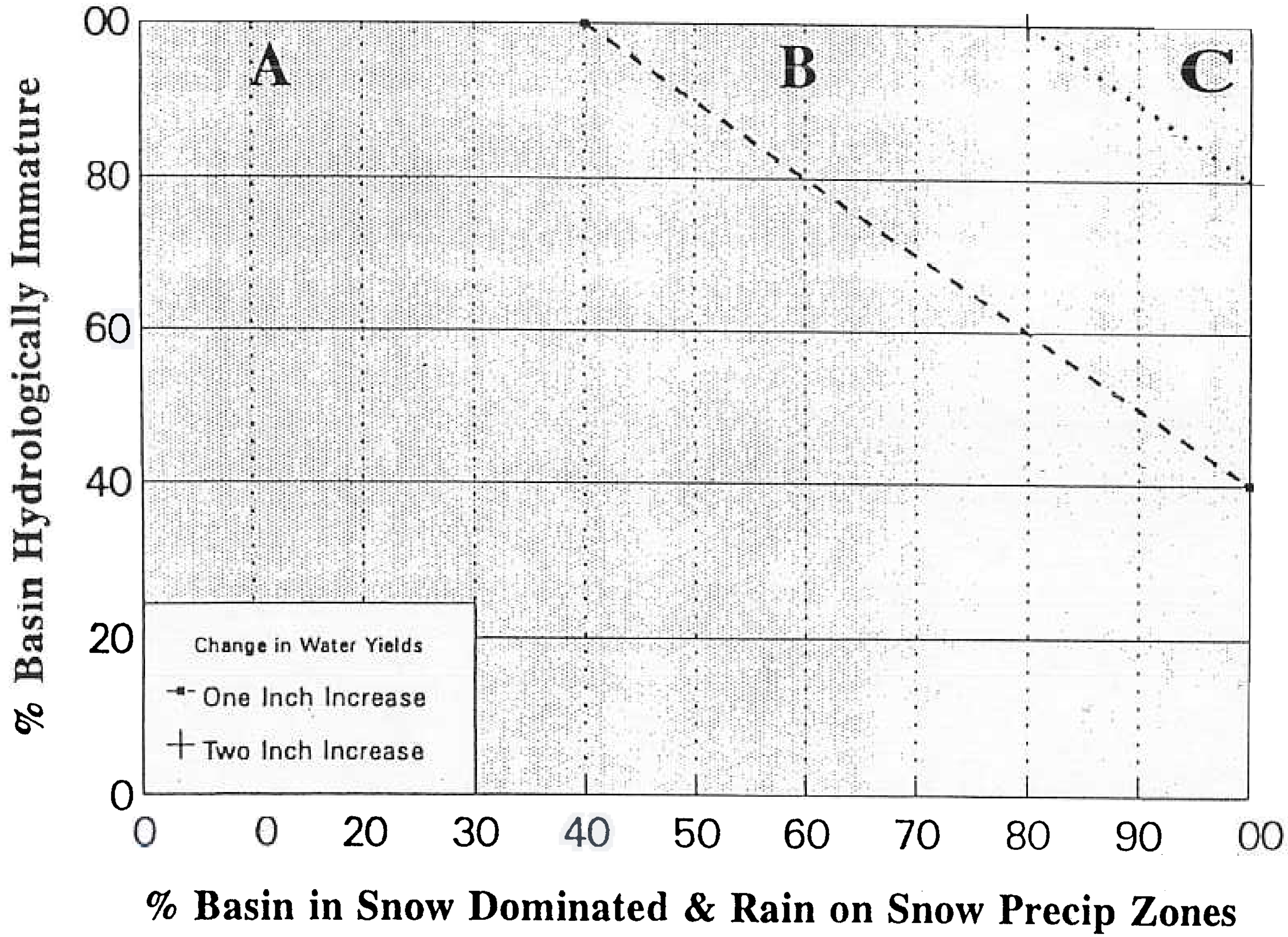
West of RMZ Line: Risk Classes

Attachment One: Conditioning Strategies, Rain-on-Snow



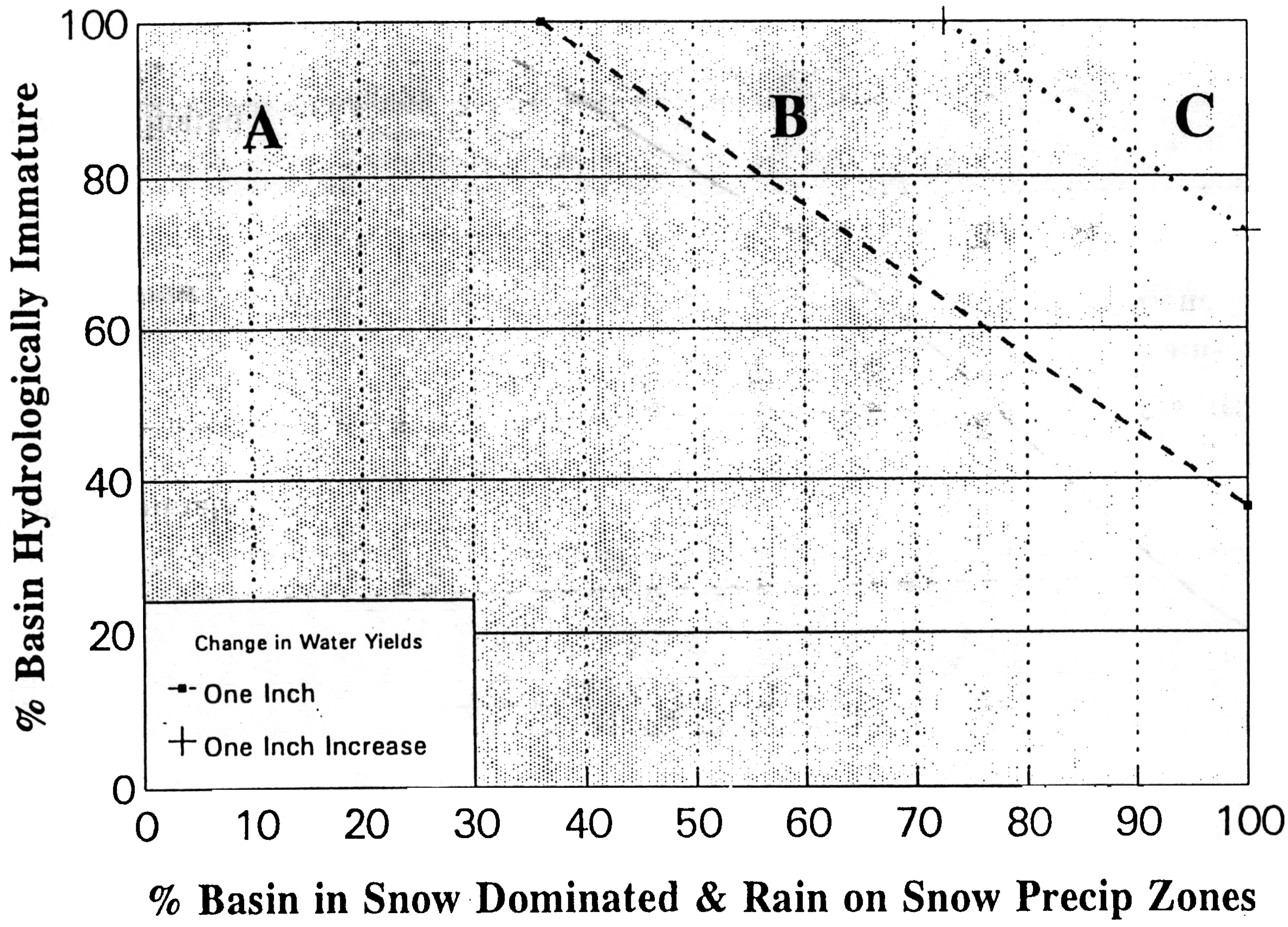
E. Cascades & Okanogan Highlands Risk Classes

Attachment Two: Conditioning Strategies Rain-on-Snow



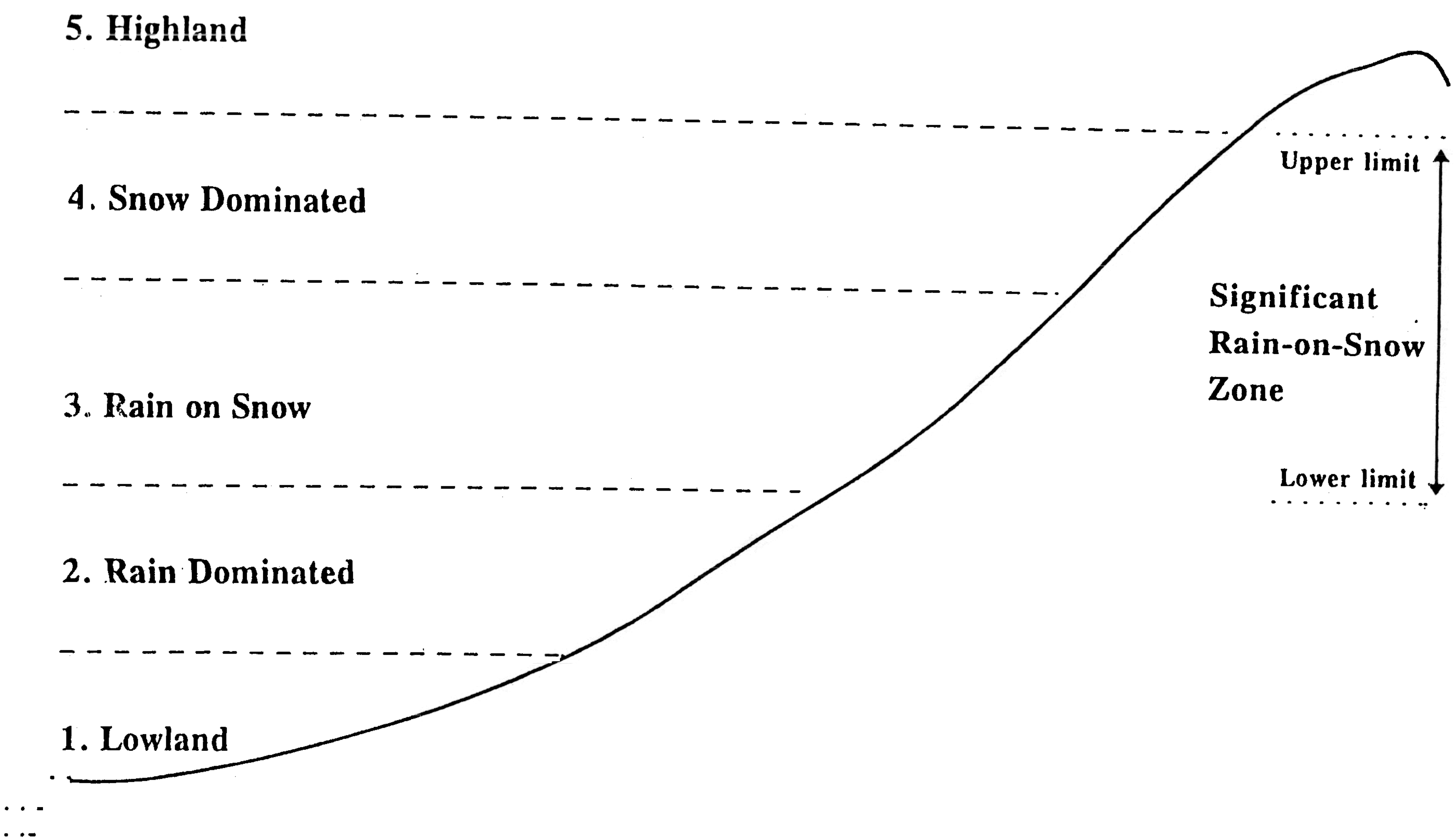
Pend Oreille & Blue Mountains: Risk Classes

Attachment Three: Conditioning Strategies, Rain-on-Snow



ATTACHMENT FOUR

Precipitation Zones



Attachment A September 26, 1991

RAIN-ON-SNOW:

WHAT IT IS, WHERE IT OCCURS, WHY WE ARE CONCERNED ABOUT IT, AND WHAT IS TO BE DONE ABOUT IT

Introduction

Many individuals and organizations involved with forest practices have become aware of the problem of rain-on-snow (R/S) storms. Within the framework of Washington forestry regulations, the issue is currently being addressed through an interim rule, while the technical arm of the Timber/ Fish/Wildlife cooperators designs methods of watershed analysis to deal with the long-term and cumulative effects of forestry on peak flows and flooding (among other things). Members of the public have also become interested, because of concern over the use of public forests and because the off-site effects of forest practices can extend into populated areas.

Many people are currently trying to design a technical and policy structure to address various forest-hydrologic issues, including that surrounding rain-on-snow events. The solutions will involve an amalgamation of applied hydrology, silviculture, remote sensing, computer modeling, geomorphology, etc. into a set of procedural, technical, regulatory, and ameliorative strategies that will be adjusted as we learn more (adaptive management).

In this paper we explain the nature of rain-on-snow events; examine the reasons that they are the subject of such attention with respect to forest-practices planning and regulation; and describe the technical basis of the procedures designed to implement the interim rule.

R/S: Processes, Occurrence, and Geography

The term **rain-on-snow** is commonly applied to snowmelt that occurs during cloudy weather, typically associated with winter storms bringing warm winds and heavy rains. Such conditions also affect the snowpack in between the storms, so in common usage R/S involves both the snowmelt during an event and to the accumulation that preceded it. Because the input to soils and streams during R/S events consists of the storm precipitation plus the release of water stored as snow, the intensity of water inputs can exceed those expected on the basis of the storm's recurrence interval (if the water has time to pass through the snowpack).

In the Pacific Northwest, this phenomenon is responsible for many (east side) to most (west side) of the greatest episodes of flooding and landsliding. Thus, anxiety over R/S focuses on the possibility of receiving more water than has been expected, predicted, or designed for; the effects on rapid runoff and slope stability; and consequent injury and damage to resources and property.

During rain-on-snow conditions, the major source of energy for snowmelt is the wind-aided transfer of sensible and latent heat to the snow surface.[1] Long-wave radiation emitted by trees, clouds, and other parts of the forest environment also contributes to snowmelt during R/S conditions. Heat added to the snowpack by the rain itself can be a major energy source, particularly when rainfall is heavy and air (thus rain) temperatures are high. Short-wave radiation (sunlight) is a minor contributor under R/S conditions, in which short winter daylight periods, low sun angles, and cloudy weather restrict insolation; this is in contrast to clear-weather snowmelt, in which sunlight is the chief source of energy for melting.

In Washington, rain-on-snow <u>can</u> occur <u>anywhere</u>, from sea level to the alpine zone. The location, timing, and frequency of R/S events are ultimately controlled by the large-scale weather patterns affecting the Pacific Ocean and western North America, as modified by the terrain of the Pacific Northwest. Therefore, the specific conditions causing such events, and hydrometeorologic behavior during them, vary somewhat in different kinds of storms, in western versus eastern Washington, and with elevation.

Winter storms can hit Washington from September to June, but are most frequent and intense from late November to early February. Many North Pacific cyclonic storms are associated with air flow from the southwest; in some cases, strong flow from the vicinity of Hawaii (the "pineapple express") causes warm, moist air to approach the coastal and Cascade ranges almost perpendicularly, causing rapid air rise, cooling, and condensation. The result is warm temperatures, strong winds, and heavy rains (orographically enhanced precipitation). If there is snow on the ground (as is likely, at least in the mountains), these situations are ideal for melt, and produce the most significant R/S events. But since most winter storms are accompanied by tempera-

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[1] Sensible heat is the warmth that can be felt, as in a home's forced-air heating system; the latent heat of vaporization is released when water vapor condenses on the snow surface.

tures above seasonal normals, lesser amounts of snowmelt can occur even under moderate storm conditions.

The degree to which a particular storm causes rain-on-snow at a particular place depends on:

1) the amount of rain delivered by the storm at the site;
2) the presence and state (depth, water content, permeability, etc.) of snow on the ground; and
3) whether the freezing level rises above the site elevation for enough time that a significant amount of snow can be melted.

Thus, R/S-event input is greatest when and where the <u>combination</u> of rainfall, melt-inducing heat sources, and meltable snow is most favorable. The effect is maximal under the storm track, on the windward sides of mountains, where/when temperatures are highest, and where the snowpack contains exactly as much water as can be released during the event. It is reduced where rainfall is less (i.e. away from the area of peak magnitude and intensity, and on leeward slopes), temperatures are cooler (at higher elevations), and the snowpack is either too thin to yield much water (lower elevations), or so thick that it inhibits the liquid water (R+SM) from reaching the soil quickly (higher elevations).

Therefore, the occurrence of rain-on-snow is a <u>probabilistic</u> phenomenon: it is the result of the interaction of many factors, each of which varies geographically and in time. However, because each of these factors has an average or most-probable condition, we can make some general statements about the likelihood and magnitude of R/S events.

Broadly speaking, the highest probability of rain-on-snow occurrence is associated with winter storms, peaking in November to February (thinner snowpacks are most vulnerable to melting earlier in this period). Because there tends to be more rain and more snow accumulation on the windward sides of mountains, the west- to southwest-facing slopes of the Cascades and Olympics generally experience the greatest R/S events. They are most likely in a range of middle elevations, where rain and snow are both common, and the freezing level fluctuates 1,000 ft or more over a series of storms. Termed the **transient snow zone**, this range of middle elevations is located at <u>approximately</u> 1,000-4,000 ft in the central-western Cascades; it is higher to the south and west, lower to the north and east. R/S events are both more frequent and (apparently) more hydrologically significant in this zone. Below it (rain-dominated zone), storms are more likely to strike bare ground, so there is little or no snowmelt contribution; higher (snow zone), storm precipitation typically falls as snow, and any liquid water is likely to be refrozen in a deep snowpack.

A somewhat different kind of rain-on-snow event occurs in the spring, when late-winter cyclonic storms or summer-season convective storms, combined with warmer temperatures and more sunlight, can rapidly melt any surviving snowpack. This can be an important process when snow persists at lower-than-normal elevations, due to heavy winter snow and/or cool wet weather in the spring; higher elevations (in the snow zone and the upper transient snow zone) are typically affected by this type of R/S. However it can be significant, especially in certain regions: although the Columbia Basin, Blue Mountains, and Okanogan Highlands are less susceptible to winter storms, they are vulnerable to springtime R/S events (as in the floods of May 1948).

Given this variability in the factors controlling R/S processes, it should be clear that delineating a rain-on-snow zone is not a trivial exercise. Since R/S can occur anywhere, the problem becomes one of identifying the places where it is most significant, in hydrologic or some other (damage ?) terms. This begs the question of degree of significance, in terms of the magnitude (simple amounts), intensity (amount per unit time), or proportional increases (relative to storm precipitation) of water input due to snowmelt: how much is important ? and how do these numbers vary regionally ?

Forest Practices and R/S

Despite the uncertainties, it can be understood that rain-on-snow events are most consequential in and around mountainous areas. This is where it rains the hardest, where there is likely to be snow available for melting, and where the gravitational gradient exists to allow the resultant runoff to cause mischief, in the form of flooding and erosion.

The mountains are also the home of most of Washington's forest land, so R/S and forestry are linked if only because they both take place in the same areas. Furthermore, forest practices can influence elements of the environment that control hydrologic processes related to snowmelt. To the extent that logging and forest roads affect snow hydrology, they could also exacerbate the rates and effects of rain-on-snow events. If so, the consequences could be transmitted out to the mountain fringe, where forests merge with agricultural, recreational, and (increasingly) residential land uses, and where most water-related resources and facilities are located. The existence and magnitude of these potential effects, and their control, form the crux of the forest practices-R/S issue.

Concern about the effects of forest clearing on the rate of water outflow from snowpacks (and thus water input to soil and streams) during rain-on-snow conditions focus on:

1) the magnitude of change in outflow that can be caused by clearcut logging;

2) the proportion of a basin that must be disturbed in order to produce a significant effect on runoff;

3) the persistence of increased outflow from a clearcut area, and the vegetation characteristics that control hydrologic recovery;

4) the possibility that changes in outflow can increase the magnitude and/or frequency of peak flows downstream;

5) the ability of any such increases to produce significant downstream flooding, channel changes, and damage to stream habitat;

6) the possibility that increased water input to soils can cause elevated rates of landsliding in clearcuts, or increased chances of debris torrents in channels;

7) the potential for forest roads to significantly amplify the damage due to R/S events, through more rapid flow routing, failure of drainage structures, or movement of fills.

Removal of forest vegetation, by harvesting (especially clearcutting) and road construction, can modify the rates of snow <u>accumulation</u> and <u>melt</u>, and consequently the rate of water outflow from snowpacks during R/S conditions. In any given event, a difference in outflow between forest and clearing may be due to differences in either or both.

Imagine a series of snowfalls, each roughly equal to the forest canopy's capacity to intercept snow, occurring at near-freezing temperatures. Most of the snow is caught by the canopy and melts there; the meltwater falls to the ground, enters the soil, and leaves the site. Under these conditions, a snowpack accumulating under forest is very wet, but shallow and discontinuous. In contrast, snow falling in a clearing is not intercepted, and so is less exposed to the heat sources so effective in melting snow in the canopy. Thus, snowpacks in clearcut areas (in middle elevations) are typically deeper and contain more water than those in adjacent forest stands. The amount of water in the snowpack[2] in clearcuts is commonly 2-3 times greater than that in adjacent forest stands.

Thus, the amount of snowfall, weather conditions (over periods of hours to weeks), and characteristics of the forest canopy are all important in determining differences in snow accumulation between forest and clearcut. Contrasts in accumulation are greatest after a series of light snowfalls at or near freezing, followed by temperatures slightly above freezing. There is little difference following prolonged snowfall at temperatures well below freezing.

The second basis for concern about effects of timber harvest involves snowmelt. Because the major source of heat for melting snow during R/S conditions is usually the wind-dependent transfer of sensible and latent heat, any activity or situation that causes increased near-surface wind speed and turbulence will likely increase the rate of heat transfer to the snow, and consequently the rate of snowmelt. Thus, the removal of trees allows more rapid melting of snow in clearings.

In the Northwest there are a vast number of possible scenarios of snow accumulation and subsequent melt, determined by the weather in the time preceding and during a storm, and by the characteristics of a particular site. Thus, differences in response between adjacent cleared and forested lands will also depend on probabilistic elements. The extreme case entails large differences between forests and clear-cuts in snow accumulation, followed by a pineapple-express storm with heavy rainfall accompanied by strong winds and high air temperatures (50-60°F): snowpacks in clear-cuts, deeper and extending to lower elevations, melt to yield much extra water, while forests at equivalent elevations receive little more than the storm precipitation. However, even the more frequent R/S scenario, with moderate amounts of rain, lesser wind speeds, and temperatures up to about 45°, can also melt snowpacks rapidly and produce differences in water outflow between forests and clearings.

If there is a difference, during a certain event or over a period of years, between the amounts of water available for runoff during R/S from adjacent forested and clear-cut areas, then the issues enumerated above become pertinent. If the amount of runoff expected from harvested areas (particular large units) will be greater than it was before cutting, we need to be able to

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[2] The snow-water equivalent (SWE), the depth of water that would result if the snow melted completely.

predict whether the increase will be large enough to cause significant modifications of soil hydrology (increased pore-water pressures leading to mass movement) or channel behavior (higher or more frequent peak flows, acceleration of sediment transport, habitat degradation). If any of these apply, we want to know how much cutting will initiate significant effects, how great they might be, what damage they might cause to resources and property in and around the forest, and how long such changes might last.

It should be clear from the preceding discussion that the answers to these questions are delicately contingent upon regional and local terrain, vegetation, and basin hydrology, and to the sequence of weather conditions up to a particular time. We would like to be able to identify the areas where hydrologic processes during R/S events will be significantly altered by timber harvest and roads, evaluate the nature and magnitude of effects, and determine how the negative effects can be prevented or mitigated (by planning, regulation, or engineering). At this point we are just beginning to be able to generalize about these subjects.

Addressing Rain-on-Snow Issues

We are addressing the what, where, and how questions of rain-on-snow through the T/F/W-CMER research program; some answers will not be available for a couple of years yet. But the existing body of research indicates that R/S is an important hydrologic process in the forested lands of Washington; and we surmise that some forest practices can cause significant changes in these processes, leading to damage in some cases. Also, because most of the effects of forest operations on rain-on-snow processes take place downstream of and later in time than the operations themselves, the interaction seems to be an example of a **cumulative effect** of forest practices on the environment. As such, the issue has become wrapped up in discussions of cumulative effects, with all the scientific and political uncertainties incumbent thereon.

Nevertheless, based on the hydrologic information that now exists and the environmental and property damage that seems to have been caused by apparent increases in peak flows, the Forest Practices Board, the Department of Natural Resources, and the Timber/Fish/Wildlife cooperators have begun to manage and regulate forest harvest so as to reduce the potential deleterious effects of large clearcuts on R/S processes.

Two interconnected approaches to the R/S issue are currently being pursued. As a result of the Sustainable Forestry Round-table and subsequent discussions, a CMER task force and the DNR were commissioned to develop methods for **watershed screening and analysis**, which would include analysis of the potential for environmental damage due to forestry-related increases in R/S frequency or magnitude. These methods are being developed; on August 14, the Forest Practices Board passed an emergency rule (WAC 222-16-046) setting deadlines for development and implementation.

Interim R/S Rules

It is expected that the results of R/S research and watershed analysis (to be done on forested basins of the state, over a period of several years) will be incorporated into the regulatory framework as the results become available. In the meantime, the Board passed a rule[3] authorizing the DNR to begin regulating clearcut size in places where R/S-related "material damage" seems to have occurred. The technical tools for identifying "significant R/S zones" are in place, and procedures for implementing the rule have been developed over the past few weeks. Creating a map delineating R/S zones has been problematic and time-consuming; and writing rules and procedures required political and administrative decisions to accept some scientific uncertainty in their formulation, and a commitment of substantial staff time in their execution. (Part of the problem was that drawing a map of significant rain-on-snow zones presupposed an agreement on a definition of "significance", which doesn't yet exist.)

However, it is possible to create a map of precipitation zones relevant to rain-on-snow processes, given a structure built around model events. We have done so, based on a variety of physical and biologic factors, encompassing available snow data, elevation, aspect, vegetation, remote imagery, and predictive models, to create proxies and indices of R/S probability. This map, and the GIS-based modeling that it will be used for, constitute the first steps in screening and analysis for R/S effects.

1. Precipitation Zones Map

Since there is no map that shows the magnitude and frequency

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[3] WAC 222-16-046 WATERSHED ANALYSIS IMPLEMENTATION

(7) Effective September 3, 1991 the department shall condition the size of clearcut harvest applications in the significant rain-on-snow zones where the department determines local evidence of peak flows which have resulted in material damage to public resources. Such conditioning authority shall expire upon completion of watershed analysis in a water-resource inventory area or sub-basin.

of water inputs to be expected from rain-on-snow events, we have attempted to create an index map based on what we know about the process controls and effects in the various climatic zones. If we assume that, averaged over many years, the seasonal storm tracks that bring warm, wet cyclonic storms to the Northwest have equal access to all parts of Washington[4], then the main factors controlling the occurrence and magnitude of a rain-on-snow event in any particular place are:

a. climatic region: especially the differences between windward and leeward sides of major mountain ranges, which control seasonal climatic patterns;

b. elevation: controls temperature, thus the likelihood and amount of snow on the ground, and affects orographic enhancement of storm precipitation;

c. latitude: affects temperature, thus snow;

d. aspect: affects insolation and temperature (especially in winter), thus melting of snow;

e. vegetation: the component species of forest communities can reflect the climate of an area (tolerance or intolerance to warmth/cold, wet/dry conditions, deep and/or long-lived snowpack); the density of vegetation also partly controls the amount of snow on the ground.

Since natural vegetation integrates the effects of all of these controls, we tried to find or adapt floral indicators of the various zones of storm-water input; unfortunately, the information is not complete or consistent for all of Washington. Thus the designation of climatic zones was based on a combination of geographic (elevation, latitude, etc.), terrain, and vegetal indicators, and our knowledge of the effects of storms in particular areas. We have extrapolated from known to lesser-known regions.

Consistent with the modeling approach, we created the precipitation zones to represent the amount of snow likely to be on the ground at the beginning of a storm. We assumed that a mid-elevation zone would experience the greatest water input due to R/S, <u>because</u> the amount of snow would be likely to be approximately the amount that could be melted. Higher and lower elevation zones would bear diminished effects, but for opposite reasons (no snow to melt, vs too cold to melt much). These considerations suggested a three- or five-zone system. We chose to

[4] A reasonable assumption for western Washington; on the east side, and particularly in northeast Washington, R/S events are less common. Model values will be adjusted, where possible, to account for these differences.

designate five zones, because it allows a finer calibration of effects in the model; also, having a larger number of classes reduces the importance of the dividing lines, and thus of the inherent uncertainties of those lines.

Thus, zones were defined based on the amount of snow that is likely to be on the ground, relative to the amount that could reasonably be melted during a model storm. We had to choose a particular time of year for the model event: because major winter storms are most common in November-February, and R/S seems to be more likely earlier in this period, a model date in early December might have been best. However, snow-survey records were an important source of snow-accumulation data, and very few surveys are carried out in December; therefore, snow amounts for early January were used.[5] The average[6] snow-water equivalents (SWE) for the early January measurements at about 100 snow courses and snow pillows were compiled; snow depths for the first week in January at about 85 weather stations[7] were converted into SWE by multiplying by 0.15 (the ratio of snow-water to depth is generally about 5-30%, depending on snow density, wetness, etc.). For each region (western North Cascades, Blue Mountains, etc.), the snow amounts were sorted by station elevation to derive a rough indicator of the relationship between snow accumulation and elevation. (Subregional differences in snow accumulation patterns were also recognized.)

The amount of snow that can be melted in a day under a particular set of R/S conditions can be estimated from a simple equation (developed by Corps of Engineers hydrologists):

$$SM_{24hr} = T_a\,[0.133 + 0.086\,v_w + 0.0126\,P_{24hr}] + 0.23$$

for SM_{24hr} = 24-h snowmelt (cm)
T_a = average air temperature (°C
v_w = average wind speed (m/sec)
P_{24hr} = 24-h precipitation (cm)

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[5] We are assuming, at this stage, that most R/S storms occur in winter; we have not attempted to model spring R/S events at this time.

[6] Based on measurements in 1961-1985, recorded in Washington Cooperative Snow Survey summaries.

[7] Also for 1961-85, or whatever part of that period was available; from National Weather Service reports on climatic data for Washington.

Assuming that temperature and wind speed are uniform, snowmelt becomes a function of precipitation. Using the 10-yr 24-hr precipitation isohyets, it was possible to estimate the regional variation in snowmelt expected from an event of that frequency. Because snowmelt is not very sensitive to precipitation amount, the differences are not great; they vary from about 2.5 in. in the Columbia Basin to about 3.5 in. in the Olympics.

The middle (or peak rain-on-snow) elevation bands were delineated as the areas where the average amount of snow (SWE) on the ground approximated these 'ideal' snow amounts; the upper and lower zones were defined by greater and lesser proportions, respectively, of these amounts. After trying various combinations of ratios for areas where the snow hydrology is relatively well known, we decided on the following designations:

5. **Highlands**: >4-5 times ideal snow amount; high elevation, with little likelihood of significant water input to the ground during storms (most precipitation as snow, and liquid water probably refreezes in a deep snowpack); effects of harvest on snow accumulation are minor;

4. **Snow-dominated zone**: from about 1.25-1.5x ideal snow amount, up to 4x; melt occurs during R/S (esp. during early-season storms), but effects can be moderated by the lag of percolation through the snowpack;

3. **Peak rain-on-snow zone**: about 0.5-0.75x up to 1.25x ideal SWE; middle elevations: shallow snowpacks are common in winter, and big storms bring much rain, so likelihood and effects of R/S are greatest; generally more snow accumulation in clearings than in forest;

2. **Rain-dominated zone**: about 0.1-0.5x ideal SWE; areas at lower elevations, where rain occasionally falls on small amounts of snow;

1. **Lowlands**: <0.1x ideal SWE; coastal, low-elevation, and rain-shadow areas; rainfall intensities are lower, and significant snow depths are rare.

Mapping of the precipitation zones was done by hand on mylar overlays on 1:250,000-scale topographic maps. Because snow depth is affected by many factors, the correlation between snow and elevation is rough, and it was not possible to simply pick out contour markers for the boundaries. Ranges of elevations were chosen for each region, but allowance was made for the effects of subregional climates, aspect, vegetational indicators of snow depth, etc. Thus, a particular boundary would have been mapped somewhat lower on the north side of a ridge or in a cooler valley (e.g. below a glacier), reflecting greater snow accumulations in such places; the same boundary would be mapped higher on the south side of the ridge, where interstorm sunshine could reduce snow accumulation. Conditions at the weather stations and snow courses were used as checks on the mapping, but in areas where measurements are scarce, some interpolation had to be performed. Attempts were made to make the mapping consistent within each region, and among adjacent regions.

The boundaries of the precipitation zones have been entered in the DNR GIS, and are available from the PR1ME computer (as FRA>GENERAL>ROS). Because of the small scale of the original mapping and the imprecision of the digitizing process, some errors have probably been introduced. It should not be expected that GIS images can be projected to large scales to find knife-edge zone boundaries, but they should be good enough to locate harvest units tens of acres or greater in size.

Some apparent anomalies in the map should be explained.

1. Much of western Washington is mapped in the lowlands or highlands zones. This does not mean that rain-on-snow does not occur in those areas; it does, but <u>on average</u> with less frequency and hydrologic significance than in the middle three zones.

2. Much of central and eastern Washington is mapped in the rain-dominated zone, despite the meager precipitation there; this means only that the amounts of snow likely to be on the ground are small, and storm-water inputs are composed dominantly of the rain itself, without much contribution from snowmelt.

3. Much of northeastern Washington is mapped in the peak R/S zone, despite the fact that such events are less common in the NE than in western Washington. This is due to the fact that much of that region is at elevations where the 'ideal' amounts of snow are liable to be on the ground when a model R/S event occurs; it does not reflect the lower <u>frequency</u> of such R/S storms in that area, which must be accounted for in other parts of the modeling and regulatory procedures.

<u>2. Zones of Interest and Threshold Graphs</u>

For the purposes of implementing the interim rule, it was decided that the 'significant rain-on-snow zones' would comprise the peak rain-on-snow and the snow-dominated zones (hereafter just 'R/S zones'). Although snowmelt also occurs with some frequency in the rain-dominated zone (on the west side, at least), the contribution to storm runoff from the lower zone is typically less than that from the higher two zones. However, applications for harvest on lands crossing the lower boundary of the R/S zones should be considered as falling under the rule. (Due to the imprecision of the mapping, areas at lower elevations might also be considered, on an exception basis.)

Once it has been established that a proposed clearcut is within the R/S zones, it must be ascertained whether there has been relevant material damage to type 3 or better waters downstream (see Attachment B). If so, it is necessary to determine whether the cutting pattern in the basin is probably causing the damage, by contributing increased runoff due to augmented snow accumulation and melt rates. In other words, it must be decided whether a sufficient proportion of the basin is covered by vegetation that is likely to be acting **hydrologically immature** (HI).

The degree to which a basin is experiencing enhanced R/S-related water input is controlled by both the proportion of the basin in the R/S zones, and the proportion of those zones covered by HI vegetation. For example, a large basin having only a few tens of acres in the significant zones is probably not going to be feeling severe R/S effects due to forest practices, even if they are completely clearcut. Likewise, even if the basin is completely in the zones of interest, there will be little effect if little of it has been cut. It is the basins where a major proportion is in the R/S zones, and a major portion of the zones are HI, that forestry-related R/S effects are most likely. Thus, it is necessary to define the basin of interest with respect to a proposed harvest, determine how much of the basin is in significant R/S zones, and estimate the portion of those zones in HI vegetation.

We are interested in basins large enough that R/S-influenced runoff effects are likely to be notable, and to affect streams having public-resource value. For these reasons it was decided that the area calculations would be made for basins of type 3 streams. In practice, areas should be defined and measured[8] upstream of the point at which a type 3 stream flows into a type 1 or 2 stream. This means that harvest applications that are completely outside such basins (in basins of type 4 or 5 streams

[8] Basin boundaries should be delineated on a topographic map, and digitized into a GIS coverage. The basin area can then be obtained from the GIS Alternately, area can be measured with a planimeter on the topographic map.

that drain directly into type 1 or 2) are not automatically regulated (they may be included by exception, though, where appropriate); however, most of the landscape is covered. The proportion of the basin within the R/S zones must also be measured.[9]

Then, for all of the land <u>in the R/S zones</u> in the defined basin, it must be determined how much of the vegetation is hydrologically immature, i.e. that has low canopy closure (density) and small tree heights. For implementation of the rule, age classes are to be used as proxies[10] for maturity: stand data, air-photos, local knowledge, etc. should be used to estimate the area in ≤25-yr (west) or ≤35-yr (east) ages.

Thus, three values will be measured: total basin area (A_b), area in the basin within the R/S zones (A_{rs}), and area in the R/S zones that is in HI vegetation (A_{hi}). Two ratios are calculated:

$$\% \text{ basin in S and R/S precip zones} = 100 * A_{rs}/A_b$$

$$\% \text{ basin hydrologically immature} = 100 * A_{hi}/A_{rs}.$$

The degree to which the combination of HI vegetation in R/S-susceptible areas can cause problems is estimated using the three graphs showing conditioning scenarios. These graphs are based on a simple model. For a basin, assume that when a storm starts the R/S zones have an ideal amount of snow on the ground (i.e. about the maximum amount meltable by a 10-yr 24-hr storm) in areas with HI vegetation, and little or no snow in adjacent forests.[11] The amount of extra snowmelt on hydrologically immature lands in R/S zones is assumed to be about 3 in. in western Washington and the upper eastern Cascades (west of the RMZ line), 2.75 in. in the Blue Mountains and in the wetter parts of northeast Washington (roughly, east of the lower Kettle-Colville-upper Little Spokane valleys), and 2.5 in. elsewhere.

The threshold lines on the graphs are based on the basin-averaged effects of snowmelt-enhanced storm-water inputs. For example, if half of a basin is in R/S zones, and half of that is

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[9] In the GIS, the precipitation zones map can be combined with the basin area to calculate this proportion.

[10] In watershed screening and analysis, Landsat images will be interpreted to evaluate actual vegetation properties relevant to hydrologic maturity.

[11] This is almost a worst-case scenario, but it is not uncommon; furthermore, it seems justified since we are considering areas where material damage has already been established.

HI, then 25% of the basin area is receiving 3 in. (west side) of vegetation-influenced SM in addition to rainfall, and the basin as a whole seems to be receiving 0.75 in. of additional storm water[12]. Alternately, if the basin has 80% in R/S zones and 65% of that in HI vegetation, the average input enhancement is 1.56 in. Points representing these cases can be located on the graphs. Note that a particular basin's position along the x-axis is set by the its area in the precipitation zones, and is unchangeable; while its position along the y-axis can change in time, depending on the rate of harvest (moves up) or the regrowth of HI vegetation (down).

The threshold lines that divide the graphs into bands represent 1 in. and 2 in. of basin-averaged, vegetation-influenced snowmelt enhancement. In very general terms, an addition of 1-2 in. of water onto a 10-yr 24-hr storm is enough to make it <u>seem</u> to the basin like a 50- to 100-yr storm[13]. We do not assume that every such situation results in parallel flood peaks (i.e., not every 50-yr storm causes a 50-yr flood). But we believe that dumping more water into streams, more often, as a result of large-scale changes in the forest can cause a general increase in peak-flow magnitudes and frequencies; and we believe that this is probably not a good outcome.

Thus, the basin in the first hypothetical case (described above) plots in the A band, in which the R/S effects are considered minor. The basin in the second case plots in the B band, in which harvest-related R/S effects are probably becoming significant, and further examination and conditioning are required.

<u>3. Conditioning Strategies</u>

Information on conditioning is contained in Hulsey's memo (Sept 26, 1991). In general, conditioning of harvest applications for reduction of R/S effects should attempt to:

1. reduce snow accumulation: arrange cutting units to maximize canopy interception and melt of snow; orient strip cuts to maximize interstorm solar melt;
2. reduce wind-affected melt rates: arrange units to reduce wind speed at the ground during R/S storms.

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[12] This amount is calculated from

$$SM_{model} = [\% \text{ R/S zones}/100] * [\% \text{ HI}/100] * 3 \text{ in}$$
$$= 50/100 * 50/100 * 3 = 0.75$$

[13] The differences between precipitation magnitudes of various frequencies vary from one place to another; these numbers are generalized.

Unfortunately, these two strategies could be in conflict on a particular site. The tactics to be used in any particular case will probably have to be based on site-specific conditions.

For strip cutting, some considerations of wind and the maximum unit proportions defined in the memo (footnotes 5 and 6) suggest limits on the strip sizes. Evidence from a few field studies indicates that strips any wider than one tree height (1H) experience wind speeds similar to those in large clearings. Thus, strips should be no greater than 1H in average width, and oriented across the dominant direction of storm winds <u>at that site</u>. For strips 1H wide, separation between strips should be at least 2H wide in risk class B (so that acreage cut is $\leq$35%); and at least 4H wide in risk class C (so acreage cut is $\leq$20%).

<u>Watershed Screening for Hydrologic Changes</u>

Within a few months, we will be conducting screening of designated basins (sub-WRIA scale) for slope instability, wildlife, fisheries, and hydrologic changes. The precipitation zone maps described above, along with other data layers and attributes, will be used to model the changes in basin storm-water input apparently due to past harvest.

<u>Conclusions</u>

We believe that rain-on-snow is an important process in the forested lands of Washington; that runoff from snowpacks during R/S events, particularly in (broadly defined) middle elevations, can be increased by certain forest practices, notably clearcut harvest; and that such changes can contribute to damage of resources and property within and outside the forest. The interest in and concern about the interaction of forest practices and R/S, by state agencies, forest land-owners and operators, other T/F/W cooperators, and the citizenry at large, are not misplaced.

However, because R/S is a natural process, the incidence and magnitude of which are controlled by many environmental factors that vary in time and space, it is difficult to define precisely when and how forest practices will cause or contribute to such damage on a particular site.

The maps, graphs, and guidelines explained here are our attempts to apply scientific knowledge and techniques to management and regulatory questions. We acknowledge that they are based on incomplete information, debatable assumptions, approximations, and model calculations; but we think that each piece is reasonably valid.

STREAM CHANNEL STABILITY FIELD EVALUATION FORM

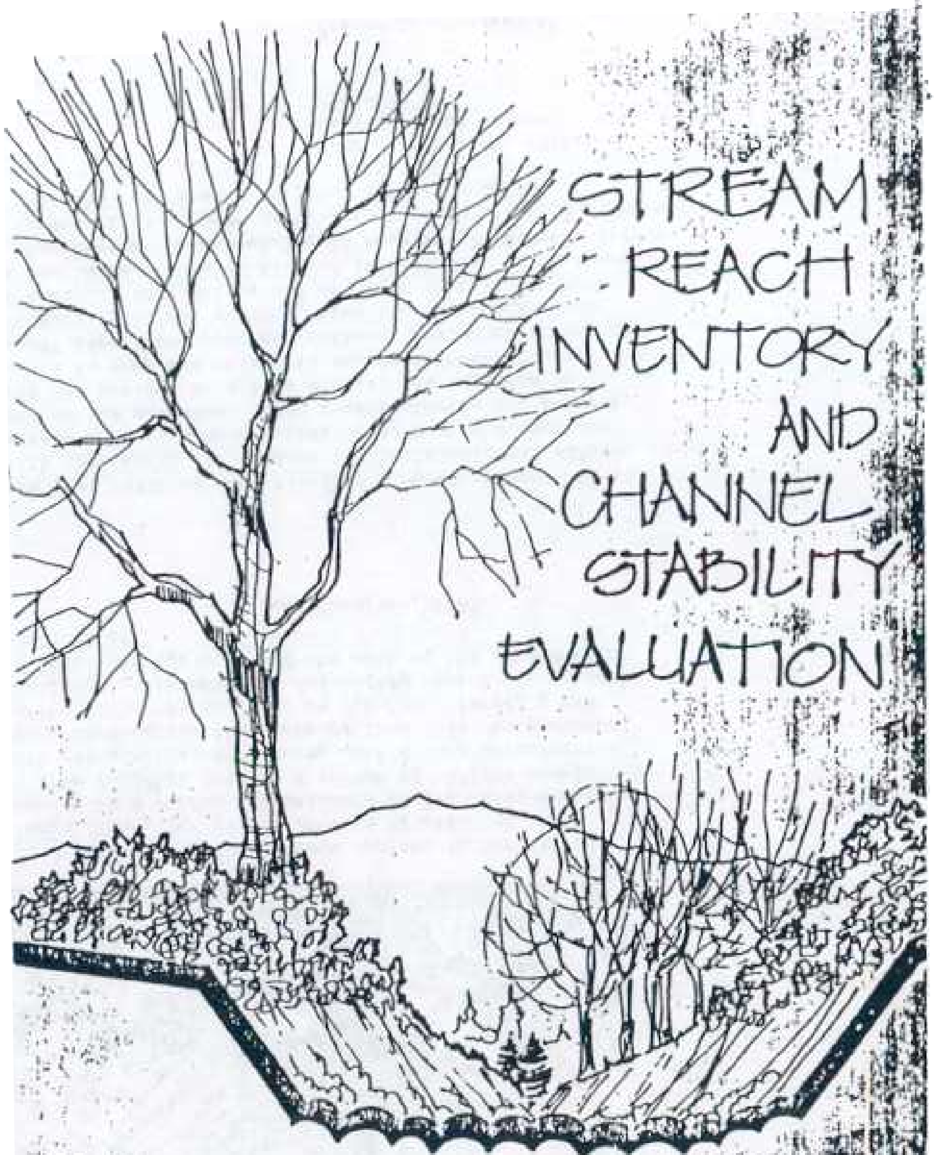
Item Rated	Stability Indicators by Classes							
	Excellent		Good		Fair		Poor	
Upper Banks								
Landform Slope	Bank slope gradiant <30%	(2)	Bank slope gradient 30-40%	(4)	Bank slope gradient 40-60%	(6)	Bank slope gradient 60%+	(8)
Mass Wasting or Failure (existing or potential)	No evidence of past or any potential for future mass wasting into channel.	(3)	Infrequent and/or very small. Mostly healed over. Low future potential.	(6)	Moderate frequency & size, with some raw spots eroded by water during high flows.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	(12)
Debris Jam Potential (Floatable Objects)	Essentially absent from immediate channel area.	(2)	Present but mostly small twigs and limbs.	(4)	Present, volume and size are both increasing.	(6)	Moderate to heavy amounts predominantly larger sizes.	(8)
Vegetative Bank Protection	90%+ plant density. Vigor and variety suggests a deep, dense, soil binding, root mass.	(3)	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	(5)	50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	(9)	<50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass.	(12)
Lower Banks								
Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	(1)	Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8 to 15.	(2)	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	(3)	Inadequate. Overbank flows common. W/D ratio >25.	(4)
Bank Rock Content	65%+ with large, angular boulders 12"+ numerous.	(2)	40 to 65%, mostly small boulders to cobbles 6-12".	(4)	20 to 40%, with most in the 3-6" diameter class.	(6)	<20% rock fragments of gravel sizes, 1-3" or less.	(8)
Obstructions Flow Deflectors Sediment Traps	Rocks & old logs firmly embedded. Flow pattern without cutting or deposition. Pools & riffles stable.	(2)	Some present, causing erosive cross currents and minor pool filling. Obstructions & deflectors newer and less firm.	(4)	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools.	(6)	Frequent obstructions & deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	(8)
Cutting	Little or none evident. Infrequent raw banks less than 6" high generally.	(4)	Some, intermittently at outcurves & constrictions. Raw banks may be up to 12".	(8)	Significant. Cuts 12"-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continous cuts, some over 24" high. Failure of overhangs frequent.	(16)
Deposition	Little or no enlargement of channel or point bars.	(4)	Some new increase in bar formation, mostly from coarse gravels.	(8)	Moderate deposition of new gravel & coarse sand on old and some new bars.	(12)	Extensive deposits of predominantly fine particles. Accelerated bar development.	(16)
Channel Bottom								
Rock Angularity	Sharp edges and corners, plane surfaces roughened.	(1)	Rounded corners and edges, surfaces smooth and flat.	(2)	Corners & edges well rounded in two dimensions.	(3)	Well rounded in all dimensions, surfaces smooth.	(4)
Brightness	Surfaces dull, darkened, or stained. Gen. not "bright".	(1)	Mostly dull, but may have up to 35% bright surfaces.	(2)	Mixture, 50-50% dull and bright, ± 15% ie. 35-65%.	(3)	Predominantely bright, 65%+, exposed or scoured surfaces.	(4)
Consolidation or Particle Packing	Assorted sizes tightly packed and/or overlapping.	(2)	Moderately packed with some overlapping.	(4)	Mostly a loose assortment with no apparent overlap.	(6)	No packing evident. Loose assortment, easily moved.	(8)
Bottom Size Distribution & Percent Stable Materials	No change in sizes evident. Stable materials 80-100%.	(4)	Distribution shift slight. Stable materials 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	(12)	Marked distribution change. Stable materials 0-20%.	(16)
Scouring and Deposition	Less than 5% of the bottom afected by scouring and deposition.	(6)	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18)	More than 50% of the bottom in a state of flux or change nearly yearlong.	(24)
Clinging Aquatic Vegetation (Moss and Algae)	Abundant. Growth largely moss-like, dark perennial. In swift water too.	(1)	Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters.	(2)	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	(3)	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	(4)

Reach Score of:

0-38 Excellent	39-51 High Good	77-89 High Fair	115-127 High Poor
	52-64 Med Good	90-102 Med Fair	128-139 Med Poor
	65-76 Low Good	103-114 Low Fair	140-152 Low Poor

APPENDIX 2

STREAM REACH INVENTORY AND CHANNEL STABILITY EVALUATION



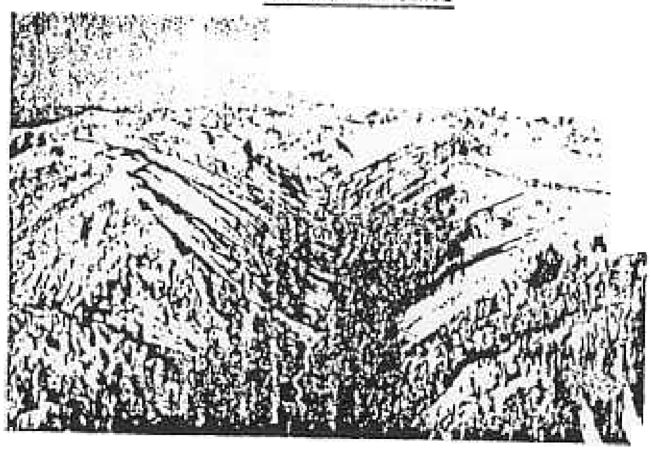
A Watershed Management Procedure

United States Department of Agriculture

Forest Service Northern Region

INDEX

ACKNOWLEDGEMENTS



Playfair's Law: *"Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys connecting with one another, and having such a nice adjustment of their declivities that none of them join the principal valley either on too high or too low a level; a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream which flows in it."*

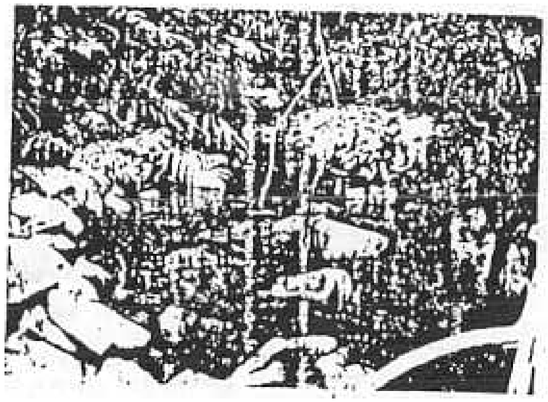
John Playfair, 1802

Others have built on John Playfair's observations. So it is with this work. Dr. Walter Megahan's original efforts at stream channel characterization in Utah a decade ago served as the stimulus. From that beginning the present system has evolved as a team effort. It has been my pleasure to shephard this work and contribute from my personal experience and observations. My Northern Region colleagues, past and present, have contributed so much in the way of suggestions and critique that it is impossible now to say "this is his and this is mine". My thanks and appreciation go especially to Dave Rosgen and Lee Silvey who labored through several revisions of the field form with me. Now the ball passes to you. Take it and run!

Dale J. Pfankuch, Forester
Lolo National Forest
Missoula, MT
June 1978

Presently Hydrologist
Rocky Mountain Region, Denver, CO

STREAM REACH INVENTORY AND CHANNEL STABILITY EVALUATION



Channel evaluations are best made during periods of low flow.

__Purpose__: These procedures were developed to systemize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recover from potential changes in flow and/or increases in sediment production.

__Uses__: The information may be gathered at a "point" for projects such as bridge sites, campground, etc., or in complete channel analyses for fisheries, timber management water balance or multiple use inventories and planning. Stream reaches may be stratified by order and geologic type and sampled to an intensity that meets survey requirements. "Point" as used here always means a reach of sufficient length to provide the observer with a range of information on which to base a sound selection from available alternatives.

__Instructions__: The card format of R-1 Form 2500-5A and this pocket field guidebook are designed to be used together - __in the field__. Use a separate rating card for each length of stream that appears similar. Identify the reach on Card Form 2500-5A, on maps and/or photos in sufficient detail so others can locate the same reach at some future time.

The inventory items are completed using maps, aerial photos and field observations and measurements. Circle all estimated data items that could be measured but weren't. The precision of measurements will be dictated by the requirements of the particular inventory. These standards should be clearly in mind when the work begins.

The evaluation portion of the inventory requires judgement based on experience and the criteria outlined in this booklet. The condition descriptions, briefly explained on the tally form, are amplified in more detail in the pages that follow. As you begin the evaluation phase of the inventory, a few words of caution are in order. Avoid keying in on a single indicator or a small group of indicators in making ratings. Since the indicators are interrelated, don't dwell on any one item for long. If all are used without bias, the maximum diagnostic value can be obtained. Do the best you can. Experience has shown that over and underratings tend to balance out. Total rating scores made by inexperienced persons are often numerically close to the scores of those with more experience.

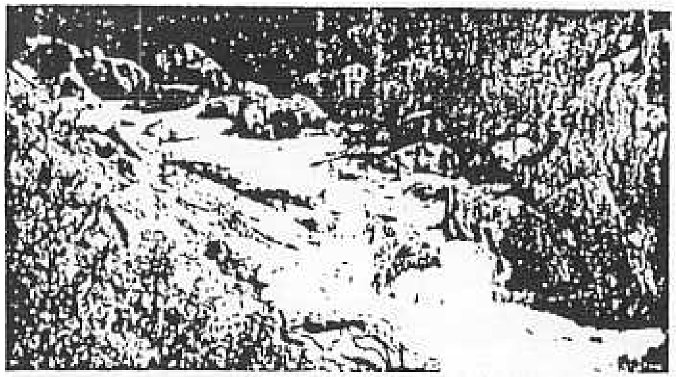
Keep in mind that each item directly or indirectly is designed to answer three basic questions:

1. What are the magnitudes of the hydraulic forces at work to detach and transport the various organic and inorganic bank and channel components?

2. How resistent are these components to the recent stream flow forces exerted on them?

3. What is the capacity of the stream to adjust and recover from potential changes in flow volume and/or increases in sediment production?

The channel and adjacent flood plain banks are subjectively rated, item by item, following an on-the-ground inspection. Circle only one of the numbers in parentheses for each item rated. If actual conditions fall somewhere between the conditions as described, cross out the number given and below it write in an intermediate value which better expresses the situation as you see it.



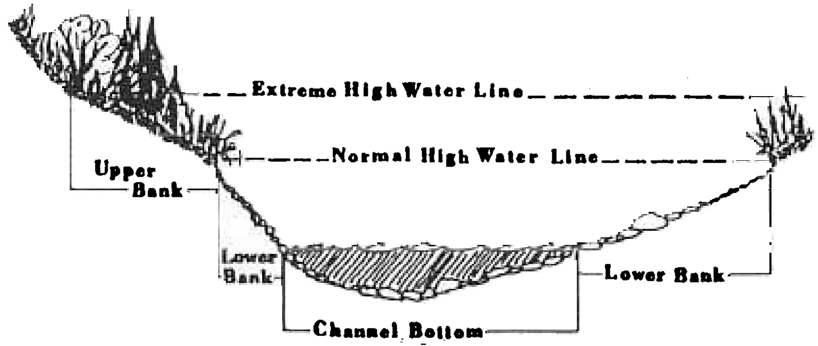
NOTE: Channels cut to bedrock are always rated Excellent.

DEFINITION OF TERMS AND ILLUSTRATIONS

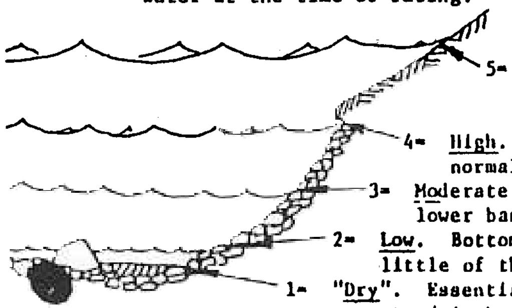
Upper Bank - That portion of the topographic cross section from the break in the general slope of the surrounding land to the normal high water line. Terrestrial plants and animals normally inhabit this area.

Lower Banks - The intermittently submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low flow period.

Channel Bottom - The submerged portion of the channel cross section which is totally an aquatic environment.



Stream Stage - The height of water in the channel at the time of rating is recorded, using numbers 1 through 5. These numbers, as shown below, relate to the surface water elevation relative to the normal high water line. A decimal division should be used to more precisely define conditions, i.e., 3.5 means 3/4ths of the channel banks are under water at the time of rating.



5- Flooding. The flood plain is completely covered.

4- High. Channel full to the normal high water line.

3- Moderate. Bottom and 1/2 of lower banks wetted.

2- Low. Bottom covered but very little of the lower banks wet.

1- "Dry". Essentially no flow. Water may stand in bottom depressions.

KEY CARD FOR FIELD FORM 2500-5A

KEY NUMBER ON FIELD CARDS

	Item Rated	
Upper Banks	Landform Slope	1
	Mass Wasting or Failure (existing or potential)	2
	Debris Jam Potential (Floatable Objects)	3
	Vegetative Bank Protection	4
Lower Banks	Channel Capacity	5
	Bank Rock Content	6
	Obstructions Flow Deflectors Sediment Traps	7
	Cutting	8
	Deposition	9
Bottom	Rock Angularity	10
	Brightness	11
	Consolidation or Particle Packing	12
	Bottom Size Distribution and Percent Stable Materials	13
	Scouring and Deposition	14
	Clinging Aquatic Vegetation (Moss and Algae)	15

R-1 STREAM REACH INVENTORY and CHANNEL STABILITY EVALUATION

REACH LOCATION: Survey Date 8-12-75 Time 1430 Obs. D.R. - L.S. - D.P.

Forest Brightwater Rgr. Dist. Purity

Stream Fern Creek P.W.I. W/S No. 16-02-00-04-23-05-01-01

Reach Description & Other Identification Road crossing Sec 3 to 1/4 mi. upstream Aerial Photo #274-191

	Key #	Stability Indicators by Classes — EXCELLENT		(Fair and Poor on reverse side) — GOOD	
Upper Banks	1	Bank slope gradient <30%.	(2)	Bank slope gradient 30-40%.	(4)
	2	No evidence of past or any potential for future mass wasting into channel.	3	Infrequent and/or very small. Mostly healed over. Low future potential.	(6)
	3	Essentially absent from immediate channel area.	(2)	Present but mostly small twigs and limbs.	4
	4	90%+ plant density. Vigor and variety suggests a deep, dense, soil binding, root mass.	3	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	(6)
Lower Banks	5	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	(1)	Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8 to 15.	2
	6	65%+ with large, angular boulders 12"+ numerous.	(2)	40 to 65%, mostly small boulders to cobbles 6-12".	4
	7	Rocks and old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable.	2	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	(4)
	8	Little or none evident. Infrequent raw banks less than 6" high generally.	(4)	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	~~(8)~~ 6
	9	Little or no enlargement of channel or point bars.	4	Some new increase in bar formation, mostly from coarse gravels.	(8)
Bottom	10	Sharp edges and corners, plane surfaces roughened.	(1)	Rounded corners and edges, surfaces smooth and flat.	2
	11	Surfaces dull, darkened, or stained. Gen. not "bright".	(1)	Mostly dull, but may have up to 35% bright surfaces.	2
	12	Assorted sizes tightly packed and/or overlapping.	2	Moderately packed with some overlapping.	(4)
	13	No change in sizes evident. Stable materials 80-100%.	4	Distribution shift slight. Stable materials 50-80%.	(8)
	14	Less than 5% of the bottom affected by scouring and deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)
	15	Abundant. Growth largely moss-like, dark green, perennial. In swift water too.	(1)	Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters.	2
		EXCELLENT COLUMN TOTAL →	24	GOOD COLUMN TOTAL →	22

Add values in each column and record in spaces below. Add column scores.

E. 24 + G. 22 + F. 6 + P. 0 = 52 Total Reach Score.

Adjective ratings: <38-Excellent, 39-76-Good, 77-114-Fair, 115+-Poor*

*(Scores above may be locally adjusted by Forest Hydrologist)

INVENTORY DATA: (observed or measured on this date) Side 2

Stream Width 6 ft.X Ave.Depth 0.5 ft.X Ave.Velocity 1.2 f/s = 3.6 Flow cfs
Reach Gradient 4 %. Stream Order 3. Turbidity Level Low. Stream Stage Low (2.3) Sinuosity Ratio 1.2.
Temperature °F or °C of: Air 86 Water 52. Others pH 7.2, Conductance 45 μMhos
Water Quality Sample Bottle # 34

Key #	Stability Indicators by Classes: FAIR		POOR	
Upper Banks				
1	Bank slope gradient 40-60%.	(6)	Bank slope gradient 60%+.	(8)
2	Moderate frequency & size, with some raw spots eroded by water during high flows.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	(12)
3	Present, volume and size are both increasing.	(6)	Moderate to heavy amounts, predominantly larger sizes.	(8)
4	50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	(9)	<50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass.	(12)
Lower Banks				
5	Barely contains present peaks. Occassional overbank floods. W/D ratio 15 to 25.	(3)	Inadequate. Overbank flows common. W/D ratio > 25.	(4)
6	20 to 40%, with most in the 3-6" diameter class.	(6)	< 20% rock fragments of gravel sizes, 1-3" or less.	(8)
7	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools.	(6)	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	(8)
8	Significant. Cuts 12"-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	(16)
9	Moderate deposition of new gravel & coarse sand on old and some new bars.	(12)	Extensive deposits of predominantly fine particles. Accelerated bar development.	(16)
Bottom				
10	Corners & edges well rounded in two dimensions.	(3)	Well rounded in all dimensions, surfaces smooth.	(4)
11	Mixture, 50-50% dull and bright, ± 15% ie. 35-65%.	(3)	Predominantely bright, 65%+, exposed or scoured surfaces.	(4)
12	Mostly a loose assortment with no apparent overlap.	(6)	No packing evident. Loose assortment, easily moved.	(8)
13	Moderate change in sizes. Stable materials 20-50%.	(12)	Marked distribution change. Stable materials 0-20%.	(16)
14	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18)	More than 50% of the bottom in a state of flux or change nearly yearlong.	(24)
15	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	(3)	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	(4)
	FAIR COLUMN TOTAL →	6	POOR COLUMN TOTAL →	0

Size Composition of Bottom Materials (Total to 100%)

1. Exposed bedrock .... 0 %	5. Small rubble, 3"-6"..... 30 %
2. Large boulders, 3'+ Dia.... 5 %	6. Coarse gravel, 1"-3".... 25 %
3. Small boulders, 1-3'....... 10 %	7. Fine gravel, 0.1-1"..... 20 %
4. Large rubble, 6"-12"....... 10 %	8. Sand, silt, clay, muck.. T %

Amplification of the Stream Channel Evaluation Items

General

Space on the field form permits only the very briefest description of the various components. This field booklet provides, in the text which follows, some of the basic rationale in support of these brief "kernels" or core thoughts. These explanations are arranged in the same order as they appear on the field form.

The channel cross section is subdivided into three components, to focus your attention on the various indicators to be subjectively evaluated. Once again, you are cautioned not to "key in" on any one item or group of items. All that have been included are interrelated and all must be used in an unbiased way to achieve consistent evaluations of the current situation.

Stream channel ratings should not be attempted without the preparation provided by this Field Guide. The language of the text has been kept rather general to avoid limiting its use as a management tool to a small geographic area. These general descriptions, coupled with your local experience, will stimulate mental images of indicator conditions which, when shared with fellow workers, will lead to consistent, reproducible ratings.

Illustrations in the text should be considered general in nature and not specific for all situations. It is suggested that local conditions be photographed and the pictures added to this Field Guide to achieve local uniformity.

A word of additional caution: Keep the scale of the reach being evaluated in context with the scale of dimensions given in the text and on the inventory form. Rating items were taylored for and best fit the 2nd to 4th order stream reaches. Very small, unbranched, first order segments will require a scaling down of sizes while the larger stream and river reaches will require some mental enlargement of the criteria given to fit the situation.

STREAM ORDER CLASSIFICATION

First order streams are unbranched reaches found usually but not exclusively at the head of drainage basins. Second order reaches are formed when two or more first order reaches come together and so on as illustrated below.

I. Upper Channel Banks

The land area immediately adjacent to the stream channel is normally and typically a terrestrial environment. Landforms vary from wide, flat, alluvial flood plains to the narrow, steep termini of mountain slopes. Intermittently this dry land flood plain becomes a part of the water course. Forces of velocity and turbulence tear at the vegetation and land. These hydraulic forces, while relatively short lived, have great potential for producing onsite enlargements of the stream channel and downstream sedimentation damage. Resistance of the component elements on and in the bank are highly variable. This section is designed to aid in rating this relative resistence to detachment and transport by floods.

A. Landform Slope: The steepness of the land adjacent to the stream channel determines the lateral extent and ease to which banks can be eroded and the potential volume of slough which can enter the water. All other factors being equal, the steeper the land adjacent to the stream, the greater the potential volume of slough materials.

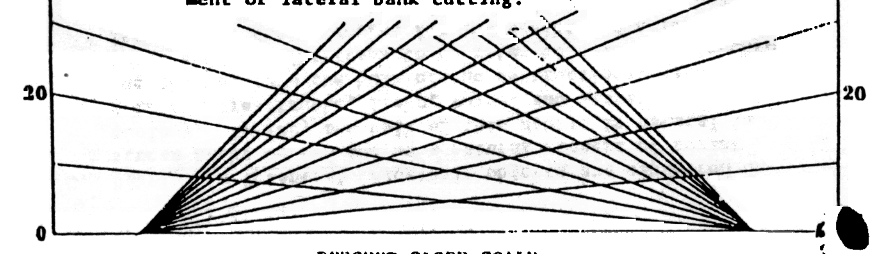
The 60% limit for poor was selected as a conservative gravitational repose angle for unconsolidated soil materials. Slopes steeper than this are rated poor because they would erode into the stream by gravity alone, if denuded of their protecting vegetation. The other ratings built on this limit and are arbitrarily set as follows:

1. Excellent: Side slopes to the channel are generally less than 30 percent on both banks.

2. Good: Side slopes up to 40% on one or occasionally both banks.

3. Fair: Side slopes to 60% common on one or both banks.

4. Poor: Steep slopes, over 60%, provide larger volumes of soil for downstream sedimentation for each increment of lateral bank cutting.



PERCENT SLOPE SCALE

Hold this page at arms length..match the slope of the topography with the percent slope lines on the scale above.

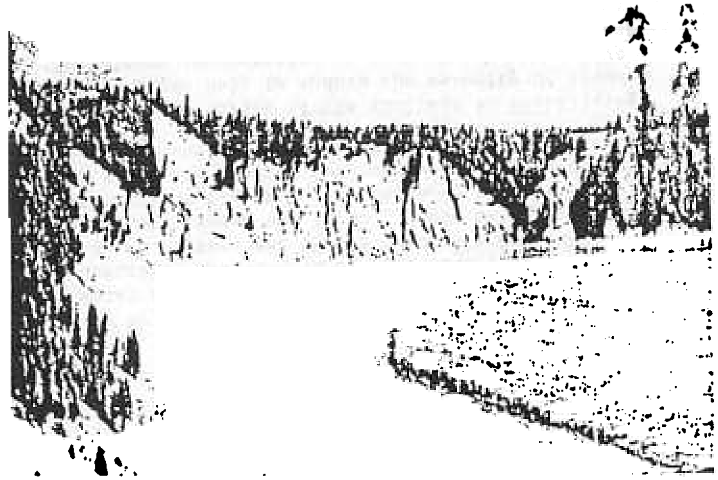
B. Mass Wasting Hazard This rating involves existing or potential detachment from the soil mantle and downslope movement into waterways of relatively large pieces of ground. Mass movement of banks by slumping or sliding introduces large volumes of soil and debris into the channel suddenly, causing constrictions or complete damming followed by increased stream flow velocities, cutting power and sedimentation rates. Conditions deteriorate in this element with proximity, frequency and size of the mass wasting areas and with progressively poorer internal drainage and steeper terrain:

1. Excellent: There is no evidence of mass wasting that has or could reach the stream channel.

2. Good: There is evidence of infrequent and/or very small slumps. Those that exist may occasionally be "raw" but predominately the areas are revegetated and relatively stable.

3. Fair: Frequency and/or magnitude of the mass wasting situation increases to the point where normal high water aggravates the problem of channel changes and subsequent undercutting of unstable areas with increased sedimentation.

4. Poor: Mass wasting is not difficult to detect because of the frequency and/or size of existing problem areas or the proximity of banks are so close to potential slides that any increases in the flow would cut the toe and may trigger slides of significant size to cause downstream water quality problems for a number of years.



Mass wasting of slopes directly into the stream channel.

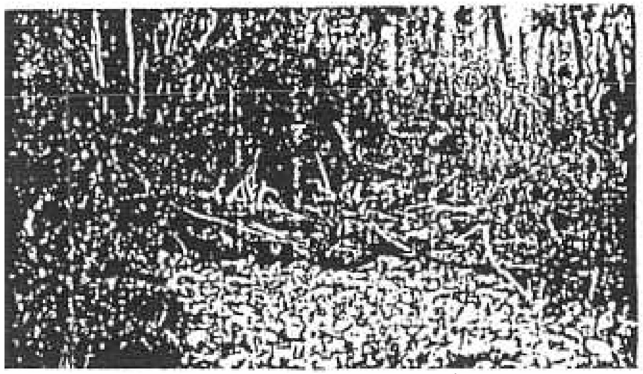
C. Debris Jam Potential Floatable objects are deposited on stream banks by man and as a natural process of forest ecology. By far, the bulk of this debris is natural in origin. Tree trunks, limbs, twigs, and leaves reaching the channel form the bulk of the obstructions, flow deflectors, and sediment traps to be rated below. This inventory item assess the potential for increasing these impediments to the natural direction and force of flow where they now lay. It also includes the possibility of creating new debris jams under certain flow conditions.

1. Excellent: Debris may be present on the banks, but is so situated or is of such a size, that the stream is not able to push or float it into the channel and, therefore, for all intents and purposes, it is absent. In truth, there may be none physically present. Both situations are rated the same.

2. Good: The debris present offers some bank protection for a while but is small enough to be floated away in time. Only small jams could be formed with this material alone.

3. Fair: There is a noticeable accumulation of all sizes and the stream is large enough to float it away, at certain times, thus decreasing the bank protection and adding to the debris jam potential downstream.

4. Poor: Moderate to heavy accumulations are present due to fires, insect attack, disease mortality, windthrow, or logging slash. High flows will float some debris away and the remainder will cause channel changes.



A series of debris jams of small size materials like the one shown in the center of this photo cause this item to be rated "Poor".

D. Vegetative Bank Protection: The soil in banks is held in place largely by plant roots. Riparian plants have almost unlimited water for both crown and root development. Their root mats generally increase in density with proximity to the open channel. Trees and shrubs generally have deeper root systems than grasses and forbs. Roots seldom extend far into the water table, however, and near the shore of lakes and streams they may be comparatively shallow rooted. Some species are, therefore, subject to windthrow.

In addition to the benefits of the root mat in stabilizing the banks, the stems help to reduce the velocity of flood flows. Turbulence is generated by stems in what may have been laminar flow. The seriousness of this energy release depends on the density of both overstory and understory vegetation. The greater the density of both, the more resistence displayed. Damage from turbulence is greatest at the bank edge and diminishes with distance from the normal channel. Other factors to consider, in addition to the density of stems, are the varieties of vegetation, the vigor of growth and the reproduction processes. Vegetal variety is more desirable than a monotypic plant community. Young plants, growing and reproducing vigorously, are better than old, decadent stands.

1. Excellent: Trees, shrubs, grass and forbs combined cover more than 90 percent of the ground. Openings in this nearly complete cover are small and evenly dispersed. A variety of species and age classes are represented. Growth is vigorous and reproduction of species in both the under- and over-story is proceeding at a rate to insure continued ground cover conditions. A deep, dense root mat is inferred.
2. Good: Plants cover 70 to 90 percent of the ground. Shrub species are more prevalent than trees. Openings in the tree canopy are larger than the space resulting from the loss of a single mature individual. While the growth vigor is generally good for all species, advanced reproduction may be sparse or lacking entirely. A deep root mat is not continuous and more serious erosive incursions are possible in the openings.
3. Fair: Plant cover ranges from 50 to 70 percent. Lack of vigor is evident in some individuals and/or species. Seedling reproduction is nil. This condition is ranked fair, based primarily on the percent of the area not covered by vegetation with a deep root mat potential and less on the kind of plants that make up the overstory.
4. Poor: Less than 50 percent of the ground is covered. Trees are essentially absent. Shrubs largely exist in scattered clumps. Growth and reproduction vigor is generally poor. Root mats discontinuous and shallow.

Lower Channel Banks

The channel zone is located between the normal high water and low water lines. Both aquatic and terrestrial plants may grow here but normally their density is sparse.

The lower channel banks define the present stream width. Stability of these channel banks is indicated under a given flow regimen by minor and almost imperceptable changes in channel width from year to year. In other words, encroachment of the water environment into the land environment is nil.

Under conditions of increasing channel flow, the banks may weaken and both cutting (bank encroachment) and deposition (bank extension) begin, usually at bends and points of constriction. Cutting is evidenced by steepening of the lower banks. Eventually the banks are undercut, followed by cracking and slumping. Deposition behind rocks or bank protrusions increase in length and depth.

As the channel is widened, it may also be deepened to accommodate the increased volume of flow. For convenience only, changes of channel bottoms are observed separately and last in this evaluation scheme.

Channel Capacity: Channel width, depth, gradient, and roughness determine the volume of water which can be transmitted. Over time channel capacity has adjusted to the size of watershed above the reach rated, to climate, and to changes of vegetation. Some indicators of change are widening and/or deepening of the channel which affects the ratio of width to depth. When the capacity is exceeded, deposits of soil are found on the banks and organic debris may be found hung up in the bank vegetation. These are expressions of the most recent flood event. Indicators of conditions as recent as a year or two ago may be difficult or impossible to find, but do your best to estimate what normal peak flows are and whether the present cross section is adequate to handle the load without bank deterioration.

Excellent: Cross sectional area is ample for present peak volumes plus some additional, if needed. Overbank floods are rare. Width to depth ratio less than 7; i.e., (36' wide ÷ 6' deep = 6).

Good: Adequate cross sectional area contains most peak flows. Width to depth ratio 8 to 15.

3. Fair: Channel barely contains the peak runoff in average years or less. Width to depth ratios range from 15 to 25.

4. Poor: Channel capacity generally inadequate. Overbank floods quite common as indicated by kind and condition of the bank plants and the position and accumulation of debris. Width to depth ratio 25 or more.

Bank Rock Content: Examination of the materials that make up the channel bank will reveal the relative resistence of this component to detachment by flow forces. Since the banks are perennially and intermittently both aquatic and terrestrial environments, these sites are harsh for most plants that make up both types. Vegetation is, therefore, generally lacking and it is the volume, size and shape of the rock component which primarily determine the resistence to flow forces.

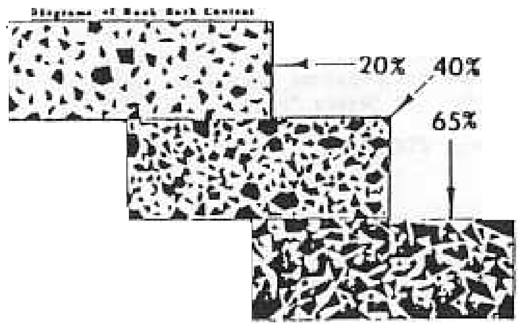
A soil pit need not be dug. Surface rock and exposed cut banks will enable you to categorize this item as listed by percentage ranges on the field form.

1. Excellent: Rock makes up 65% or more of the volume of the banks. Within this rock matrix large, angular boulders 12" (on their largest axis) are numerous.

2. Good: Banks 40-65% rock which are mostly small boulders and cobble ranging in size from 6-12" mean diameter. Some may be rounded while others are angular.

3. Fair: 20-40% of bank volume rock. While some big rock may be present, most fall into the 3-6" diameter class.

4. Poor: Less than 20% rock fragments, mostly of gravel sizes 1-3" in diameter.



C. Obstructions and Flow Deflectors: Objects within the stream channel, like large rocks, embedded logs, bridge pilings, etc., change the direction of flow and sometimes the velocity as well. Obstructions may produce adverse stability effects when they increase the velocity and deflect the flow into unstable and unprotected banks and across unstable bottom materials. They also may produce favorable impacts when velocity is decreased by turbulence and pools are formed.

Sediment Traps: Channel obstructions which dam the flow partly or wholly form pools or slack water areas. The pools lower the channel gradient. With this loss of energy the sediment transport power is greatly reduced. Coarse particles drop out first at the head of the pool. Some or all of the fine suspended particles may carry on through.

Embedded logs and large boulders can produce very stable natural dams which do not add to channel instability. Some debris dams and beaver dams, however, are quite unstable and only serve to increase the severity of channel damage when they break up.

The effectiveness of these sediment traps depends on pool length relative to entrance velocity. The swifter the current, the longer the pool needed to reach zero velocity. Turbulence caused by a falls at the head of the pool shortens the length required to reach zero velocity.

How long these traps are effective depends on depth and width as well as pool length and, of course, the rate of sediment accretion.

Items of vegetation growing in the water, like alders, willows, cattails, reeds, and sedges are also effective traps in some locations and reduce flow velocity and sediment carrying power.

Overturned shoreline trees become obstructions and flow deflectors as shown here. If frequent in the reach, rate this item "Poor".

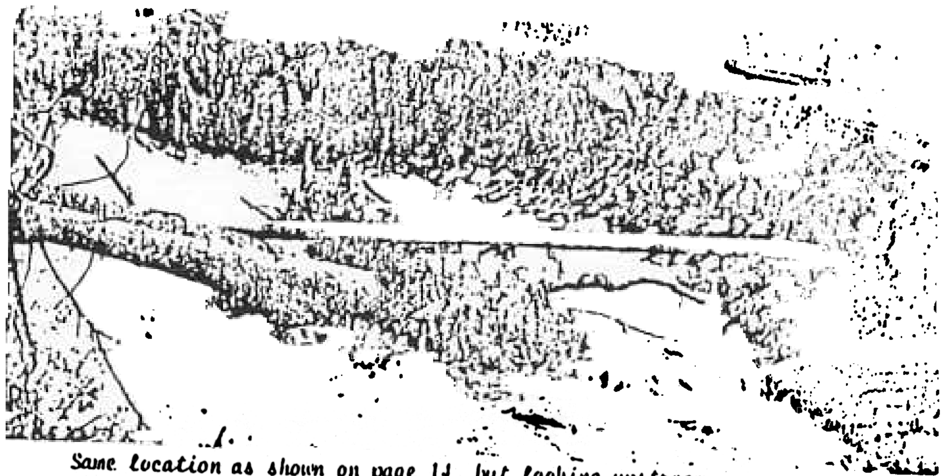
C. Obstructions and Flow Deflectors (Continued)

1. Excellent: Logs, rocks, and other obstructions to flow are firmly embedded and produce a pattern of flow which does not erode the banks and bottom or cause sediment buildups. Pool riffle relationship stable.

2. Good: Obstructions to flow and sediment traps are present, causing cross currents which create some minor bank and bottom erosion. Some of the obstructions are newer, not firmly embedded and move to new locations during high flows. Some sediment is trapped in pools decreasing their capacity.

3. Fair: Moderately frequent and quite often unstable obstructions, cause noticeable seasonal erosion of the channel. Considerable sediment accumulates behind obstructions.

4. Poor: Obstructions and traps so frequent they are intervisible, often unstable to movement and cause a continual shift of sediments at all seasons. Since traps are filled as soon as formed, the channel migrates and widens.



Same location as shown on page 14, but looking upstream. Obstruction like this could become the nucleus of a debris jam.

Cutting and Deposition are concommittent processes. You can't have one without the other. However, it is possible for each to be taking place in different reaches of the same stream at the same time, and hence the separation for classification purposes which follows.

D. Cutting: One of the first signs of channel degradation would be a loss of aquatic vegetation by scouring or uprooting. Some channels are naturally devoid of aquatic plants and here the first stages would be an increase in the steepness of the channel banks. Beginning near the top, and later extending in serious cases to the total depth, the lower channel bank becomes a near vertical wall.

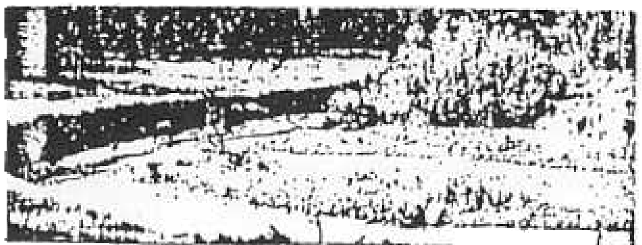
If plant roots bind the surface horizon of the adjacent upper bank into a cohesive mass, undercutting will follow. This process continues until the weight of overhang causes the sod to crack and subsequently slump into the channel. Differential horizontal compaction and texture could also result in undercut banks even with an absence of vegetative cover. There are some loosely consolidated banks that with or without vegetation are literally nibbled away, never developing much, if any, overhang.

1. Excellent: Very little or no cutting is evident. Raw, eroding banks are infrequent, short and predominately less than 6" high.

2. Good: Some intermittent cutting along channel outcurves and at prominent constrictions. Eroded areas are equivalent in length to one channel width or less and the vertical cuts are predominately less than 12".

3. Fair: Significant bank cutting occurs frequently in the reach. Raw vertical banks 12" to 24" high are prevalent as are root mat overhangs and sloughing.

4. Poor: Nearly continuous bank cutting. Some reaches have vertical cut faces over 2 feet high. Undercutting, sod-root overhangs and vertical side failures may also be frequent in the rated reach.



Poor bank conditions at this bend are evident.

E. Deposition: Lower bank channel areas are generally the steeper portions of the wetted perimeter and may be rather narrow strips of land that offer slight opportunity for deposition. Exceptions to this statement abound since deposition is often noted on the lee side of large rocks and log deflectors which form natural jetties. However, these deposits tend to be short and narrow. On the less steep, lower banks, deposition during recession from peak flows can be quite large. The appearance of sand and gravel bars where they did not previously exist may be one of the first signs of upstream erosion. These bars tend to grow, primarily in depth and length, with continued watershed disturbance(s). Width changes are in a shoreward direction as overflow deposition takes place on the upper banks. Dimensional deposition "growth" is limited by the size and orientation of the obstructions to flow along the channel bank's, flow velocity and a continuing upstream sediment supply.

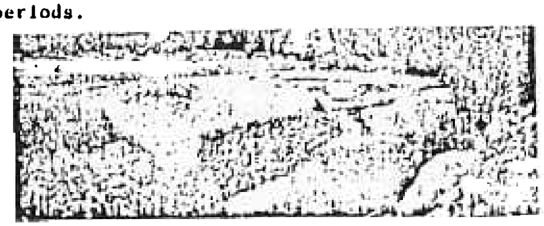
Deposition may also occur on the inside radii of bends, particularly if active cutting is taking place on the opposite shore. Also, deposits are found below constrictions or where there is a sudden flattening of stream gradient as occurs upstream above geologic nic points.

1. Excellent: Very little or no deposition of fresh silt, sand or gravel in channel bars in straight reaches or point bars on the inside banks of curved reaches.

2. Good: Some fresh deposits on bars and behind obstructions. Sizes tend to be predominately from the larger size classes - coarse gravels.

3. Fair: Deposits of fresh, coarse sands and gravels observed with moderate frequency. Bars are enlarging and pools are filling so riffle areas predominate.

4. Poor: Extensive deposits of predominately fresh, fine sands, some silts, and small gravels. Accelerated bar development common. Storage areas are now full and sediments are moving even during low flow periods.



II. Channel Bottom

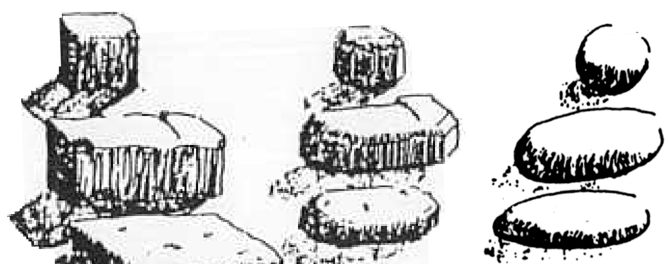
Water flows over the channel bottom nearly all of the time in perennial streams. It is, therefore, almost totally an aquatic environment, composed of inorganic rock constituents found in an infinite variety of kinds, shapes, and sizes. It is also a complex biological community of plant and animal life. This latter component is more difficult to discern and may in fact, at times and places, be totally lacking.

Both components, by their appearance alone and in combination, offer clues to the stability of the stream bottom. They are arbitrarily separated and individually rated for convenience and emphasis during the evaluation process. Because of the high reliance on the visual sense, inventory work is best accomplished during the low flow season and when the water is free of suspended or dissolved substances. If ratings must be made in high flow periods, sounds of movement may be the only clue as to the state of flux on the bottom.

A. Angularity: Rocks from stratified, metamorphic formations break out and work their way into channels as angular fragments that resist tumbling. Their sharp corners and edges wear and are rounded in time, but they resist the tumbling motion. These angular rocks pack together well and may orient themselves like shingles (imbricated). In this configuration they are resistant to detachment.

In contrast, igneous rocks often produce fragments that round up quickly, pack poorly and are easily detached and moved downstream.

Excellent to Poor ratings relate to the amount of rounding exhibited and, secondarily, the smoothness or polish the surfaces have achieved. Some rocks never do smooth up in the natural environment, but most round up in time. Both conditions, of course, are relative within the inherent capability of the respective rock types.



Subangular Rounded

Angular

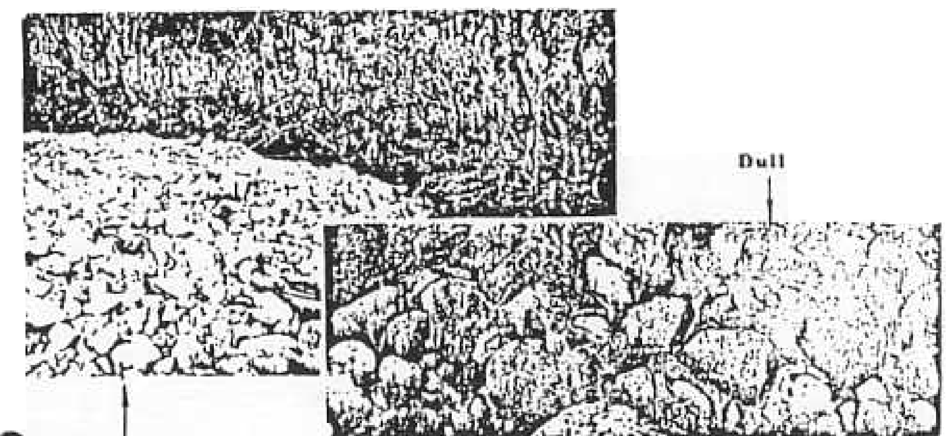
B. Brightness: Rocks in motion "gather no moss", algae or stain either. They become polished by frequent tumbling and, as a general rule, appear brighter in their chroma values than similar rocks which have remained stationary. The degree of staining and vegetative growths relate also to water temperature, seasons, nutrient levels, etc. In some areas a "bright" rock will be "dulled" in a matter of weeks or months. In another it may take years to achieve the same results. Nevertheless, even slight changes during the spring runoff should be detectable during the next summer's survey. Look first for changes in the sands and gravels.

1. Excellent: Less than 5% of the total bottom should be bright, newly polished and exposed surfaces. Most will be covered by growths or a film of organic stain. Stains may also be from minerals dissolved in the water.

2. Good: 5 to 35% of the bottom appears brighter, some of which may be on the larger rock sizes.

3. Fair: About a 50-50 mixture of bright and dull with a 15% leeway in either direction (i.e., a range of from 35 to 65% bright materials).

4. Poor: Bright, freshly exposed rock surfaces predominate with two-thirds or more of the bottom materials in motion recently.



Dull

Mostly Bright

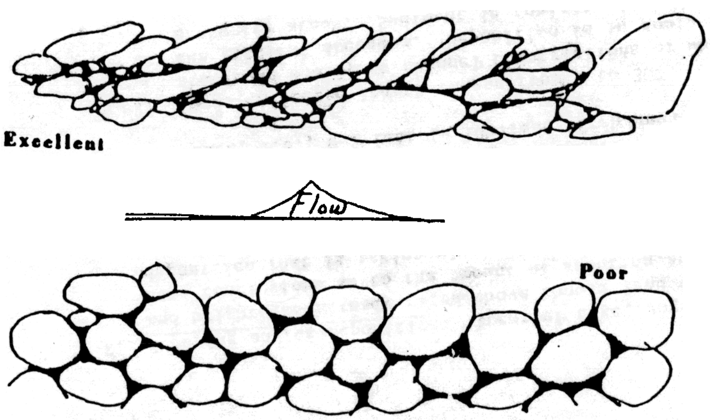
C. <u>Consolidation (Particle Packing)</u>: Under stable conditions, the array of rock and soil particle sizes pack together. Voids are filled. Larger components tend to overlap like shingles (imbricate). So arranged, the bottom is quite resistent to even exceptional flow forces. Some rock types (granitics) are less amenable to this packing process and never reach the stable state of others like the Belt Series rocks.

1. <u>Excellent</u>: An array of sizes are tightly packed and wedged with much overlapping which makes it difficult to dislodge by kicking.

2. <u>Good</u>: Moderately tight packing of particles with fast water parts of the cross section protected by overlapping rocks. These might be dislodged by higher than average flow conditions, however.

3. <u>Fair</u>: Moderately loose without any pattern of overlapping. Most elements might be moved by average high flow conditions.

4. <u>Poor</u>: Rocks in loose array, moved easily by less than high flow conditions and move underfoot while walking across the bottom. The shape of these rocks tends to be predominantly round and sorted so that most are of similar size.



Side Views of Substrate

D. <u>Bottom Size Distribution and Percent Stable Materials</u>:

Rocks remaining on a stream's bottom reflect the geologic sources within the basin and the flow forces of the past. Normally, there is an array of sizes that you expect to see in any given local. After a little experience, you begin to "sense" abnormal situations. Generally, in the mature topography typical of the Northern Region of the Forest Service and much of the other western Regions as well, the flow in the small, steep upper stream reaches is sufficient to wash the soil separates and some of the gravels away. What remains is a gravelly, cobbly stream bottom. In the lower reaches where the gradient is less and flow is often slower, deposition of the "fines" eroded above begin to drop out. The separates of sand, silt, and some clay begin to cover the coarser elements. Except where trapped in still water areas, these fines tend to be in constant motion to ever lower elevations.

Two elements of bottom stability are rated in this item: (1) Changes or shifts from the natural variation of component size classes and (2) the percentage of all components which are judged to be stable materials. Bedrock, large boulders, and cobble stones ranging in size from one to three feet or more in diameter are considered "stable" elements in the average situation. Obviously, smaller rocks in smaller channels might also be classed as stable. The sizes are given only to guide thought. <u>Bedrock</u> as a major component of bottom and banks, no matter what size the channel or how the other elements rate, <u>always</u> results in an <u>excellent</u> classification of that reach.

1. <u>Excellent</u>: There is no noticeable change in size distribution. The rock mixture appears to be normal for the kind of geologic sources in the basin and the flow forces of streams of this size and location in the watershed.

   If a shift or change has taken place so there are greater percentages of large rock in the small streams and smaller sizes in large streams, the condition class most appropriate should be checked. It is a matter of degree as follows:

   (Stable Materials 80-100%).

2. <u>Good</u>: Slight shift in either direction.

   (Stable Materials 50-80%).

3. <u>Fair</u>: Moderate shift in size classes.

   (Stable Materials 20-50%).

4. <u>Poor</u>: Marked, a pronounced shift.

   (Stable Materials less than 20%).

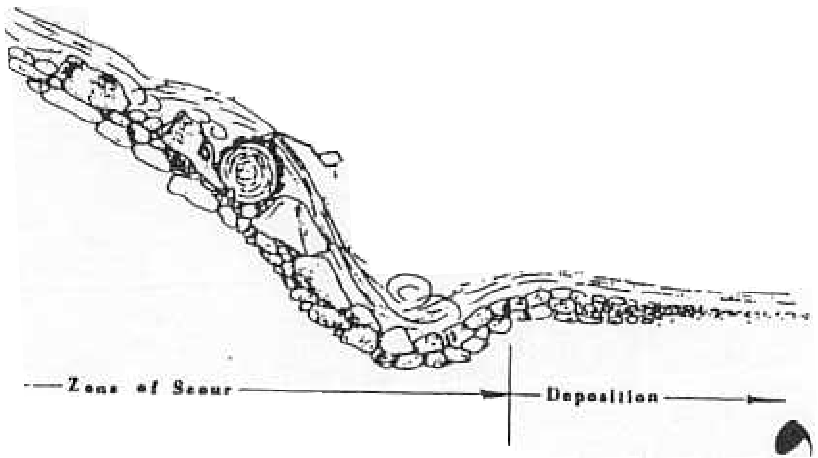
E. Scouring and/or Deposition: Items of size, angularity and brightness already rated above should lead you to some conclusions as to the amount of scouring and/or deposition that is taking place along the channel bottom.

1. Excellent: Neither scouring nor deposition is much in evidence. Up to 5% of either or a combination of both may be present along the length of the reach; i.e., 0-5 feet in 100 feet of channel length.

2. Good: Affected length ranges from 5 to 30%. Cuts are found mostly at channel constrictions or where the gradient steepens. Deposition is in pools and backwater areas. Sediment in pools tends to move on through so pools change only slightly in depth but greatly in composition of their size classes.

3. Fair: Moderate changes are occurring. 30 to 50% of the bottom is in a state of flux. Cutting is taking place below obstructions, at constrictions and on steep grades. Deposits in pools now tend to fill the pool and decrease their size.

4. Poor: Both cutting and deposition are common; 50% plus of the bottom is moving not only during high flow periods but at most seasons of the year.



Aquatic Vegetation: When some measure of stabilization of the soil-rock components is achieved, the channel bottom becomes fit habitat for plant and animal life. This process begins in the slack water areas and eventually may include the swift water portions of the stream cross section. With a change in volume of flow and/or sedimentation rates, there may also be a temporary loss of the living elements in the aquatic environment. This last item attempts to assess the one macro-aquatic biomass indicator found to best express a change in channel stability.

Clinging Moss and Algae: These lower plant forms do not have roots but cling to the substrate. They are low growing and may first appear as a green to yellow-green slick spot on the bottom rocks. Moss plants continue with slight variation in color but no great change in mass form season to season. Algae by contrast have a peak of growth activity and then die off in great numbers. The slippery conditions they produce persist after death, however.

Both algae and moss inhabit the swift water areas as well as the quiet pools and backwater portions of the stream bottom.

1. Excellent: Clinging plants are abundant throughout the reach from bank to bank. A continuous mat of vegetation is not required but moss and/or algae are readily seen in all directions across the stream.

2. Good: Plants are quite common in the slower portions of the reach but thin out or are absent in the swift flowing portions of the stream.

3. Fair: Plants are found but their occurrence is spotty. They are almost totally absent from rocks in the swifter portions of the reach and may also be absent in some of the slow and still water areas.

4. Poor: Clinging plants are rarely found anywhere in the reach. (This is an unusual situation but could happen under a combination of adverse environmental conditions).

Channels with this much moss are rated "Excellent"

Management Implications

After beating the brush, getting your feet wet and fighting insects, you have established a series of channel ratings. You may now ask, "What do these numbers mean and how are they used in making a management decision?".

By now you know this subject is complicated and precludes indepth answers here. The following brief answers may satisfy you or they may raise more questions. When this happens, it's time to consult your Forest hydrologist for detailed, specific answers.

The numbers and the adjective ratings they relate to mean what they say. A stream channel reach that rates "poor" has a combination of attributes that will require more judicious upstream management of the tributary watershed lands than one rated "excellent". This rating procedure was not designed to fix blame for poor land and water management or to reward good management, although, in time, it could be used for this purpose. Before passing judgment, be aware that natural, undistrubed watersheds may exhibit poor hydologic conditions. Conversely, a highly developed and used watershed may have a drainage network in good hydologic shape. The rating system will therefore have the most value to land managers who have definite water management goals, who can relate these to impacts of other resource uses and activities, who understand natural limitations, and who are willing and able to use the system to define the risks they are willing to take to maintain or alter the status quo.

One use of this rating system is to assess conditions and define impacts along short reaches of stream. Channel conditions can be evaluated in terms of stream stability and potential for damaging water quality at culvert and bridge sites, at campgrounds and administrative sites or wherever livestock and wildlife concentrate near or across a water course. A channel rated "poor" at a culvert site, for example, cannot withstand as much constriction or gradient change as one rated "good". Armed with this additional knowledge, the decision could be to change locations, redesign the intallation or select a different type of structure to protect the aquatic habitat.

The primary use of this system is to assess entire channel systems within a watershed and to use the results in conjunction with other hydrologic analyses to augment silvicultural prescriptions. Rapid changes in the density and areal extent of vegetation on a watershed can increase stream discharges. Channel systems rated "excellent"

can withstand these increases with less damage than systems rated "poor". "Poor" systems can withstand gradual changes better than abrupt changes in the discharge regimen.

To calculate an overall rating for a stream system, (1) multiply the length of each reach by its numeric rating, (2) add the weighted products of all reaches in the system and (3) divide by the total length of the system.

For example:

Reach A	:	3.2 miles x 80 (fair)	= 256
Reach B	:	0.5 miles x 100 (poor)	= 50
Reach C	:	2.0 miles x 40 (good)	= 80
Total	:	5.7 miles	386

Stream system average: 386 ÷ 5.7 = 68 (Good)

Land and water should not be managed on the basis of averages. In the above example, the stream system is composed of three reaches which rate "good" on the average, but a "weak link" has been identified. Reach B is in "poor" condition. One of the obvious uses of this system is to identify "weak links" and to discover what, if any, opportunity exists to correct the condition. It matters little if the damaged area is natural or man-caused. The discovery of "weak links" should reasonably alter upstream land management to the extent necessary to achieve stated land and water management objectives.

The procedures should ultimately serve as a check and a measure of management success. The net effects of each new increment of change within the watershed management unit will ultimately be expressed in the condition of the stream channel responding to a new hydraulic regimen. Prudent managers will seek these trend data by periodic reappraisal of channel conditions and respond to adverse changes before impacts to the water resource become unacceptable and unalterable.